NEW

All About Space

TOUR OF THE UNIVERSE

An awe-inspiring journey through space

Solar System • Exploration • Space Science • Deep Space

Welcome to the All About Space Tour of the Universe

Once upon a time, a man named Neil Armstrong stepped onto the surface of the Moon, declaring it "One small step for man, one giant leap for mankind." Join us as we step further than you have ever imagined across our Solar System and out into deep space. In this new revised edition, we journey through the Milky Way, our home galaxy and explore the violent surface of our star, the Sun. You will find out all about the ongoing search for extra terrestrial life, and discover the real science of interstellar space travel which has inspired science fiction and fired the imaginations of many. There are so many incredible phenomena to be found in the universe, and you'll find the greatest and most awe-inspiring here. From colonies on the Moon to the volcanoes of Io and ice geysers in space, prepare to be astonished by the wonder of the universe we live in.

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Tour of the Universe

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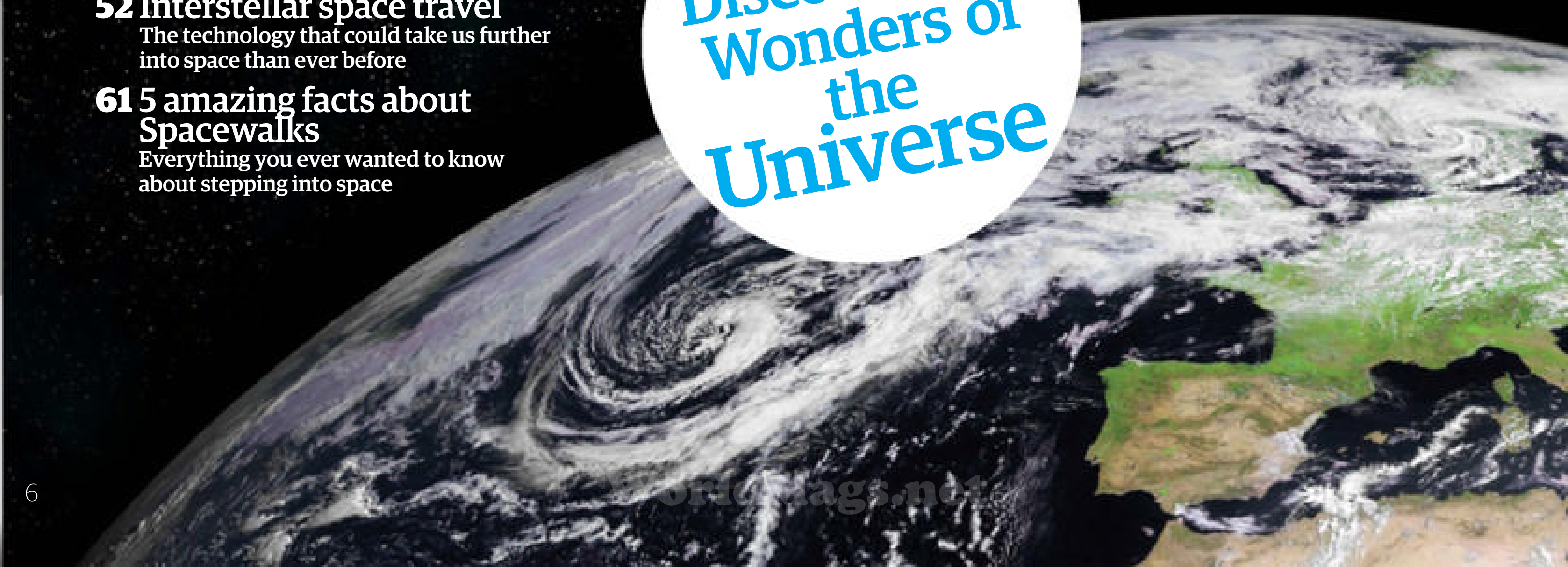


Into Deep Space

Discover the Wonders of the Universe

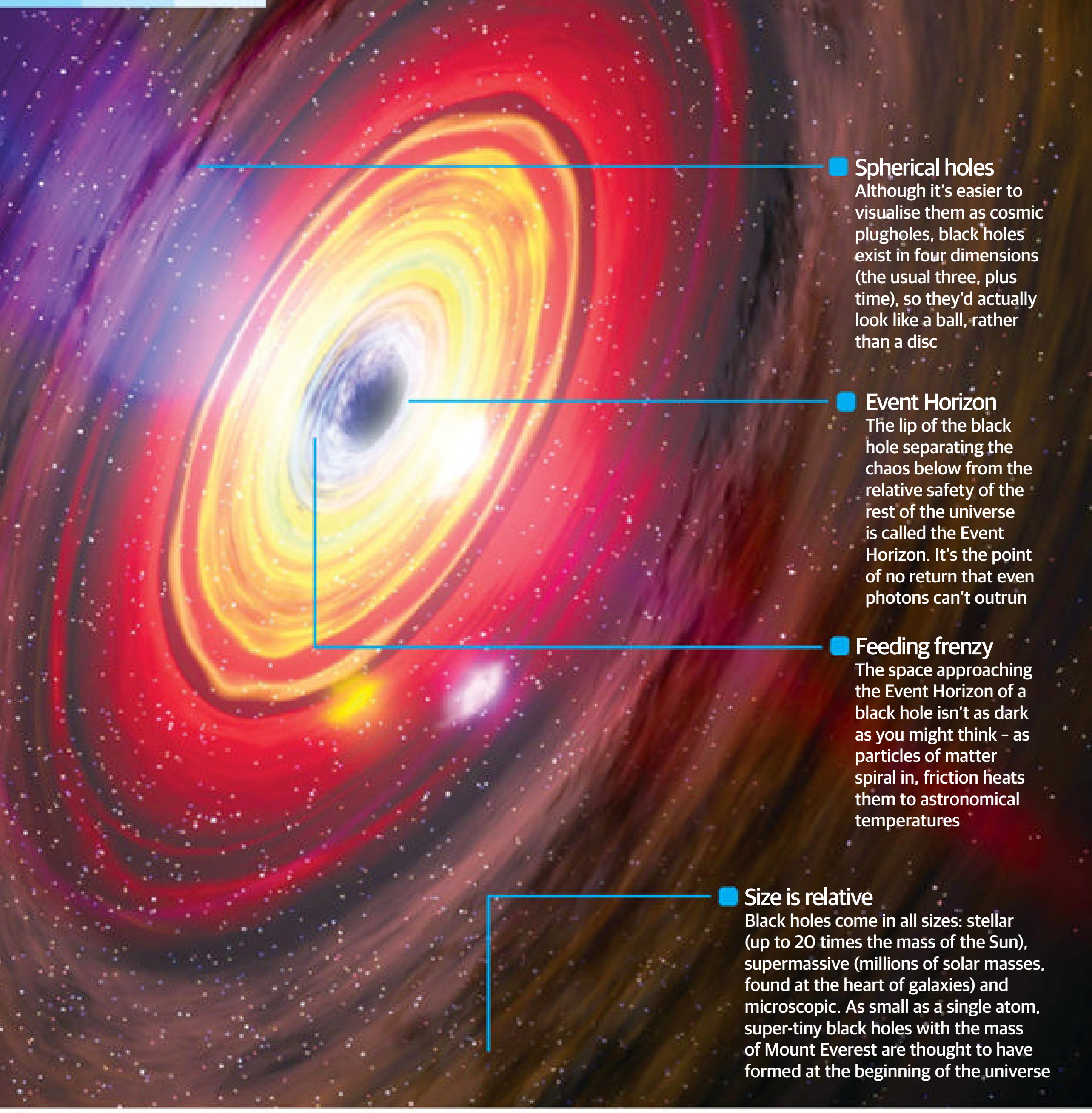
Discover the Wonders of the Universe

From exploring our Solar System to the mysteries of deep space, find out what makes our universe so amazing

What is a black hole?

All sorts of weird and wonderful things can happen when a star dies, such as neutron stars and white dwarfs. Undoubtedly the weirdest of them all, however, are the birth of stellar black holes. Like all the best enigmas of the universe, black holes are as misunderstood as they are mysterious and as hard to observe as they are to comprehend.

Stellar black holes are most commonly formed from the remnants of particularly massive stars when they die – their cores collapsing with a staggering force that defies our understanding of the laws of physics. As the star's mass is forced into an ever-smaller space, the gravitational forces involved effectively rips a hole in the fabric of the universe creating a singularity – the point at which all calculations break down, resulting in infinite loop instead of a number. The end result? The total and utter annihilation of matter and an 'ERROR' screen on the physicist's calculator.



How the universe will end

Without the theory of the Big Bang we wouldn't have much to go on when it comes to estimating what the fate of the universe may be. Thankfully, we can come up with several theories for how the universe might end based on our observations of the cosmos, namely that it appears to be expanding at an accelerating rate, but some theories suggest this won't be the case forever.

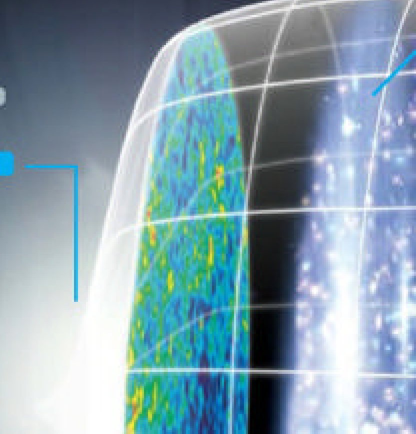
For example, the False Vacuum theory states that a so-called 'metastability event' could cause the vacuum of space to 'ping' into a lower energy state changing the rules of space, time and matter. If this is the case the entire universe could end at any moment.

Other popular views on when and how the universe will end include the Big Crunch, which is the theory that the universe will eventually start shrinking back to a singularity and re-spawn a new universe, possibly signifying the endless cycle of our universe's life and death.

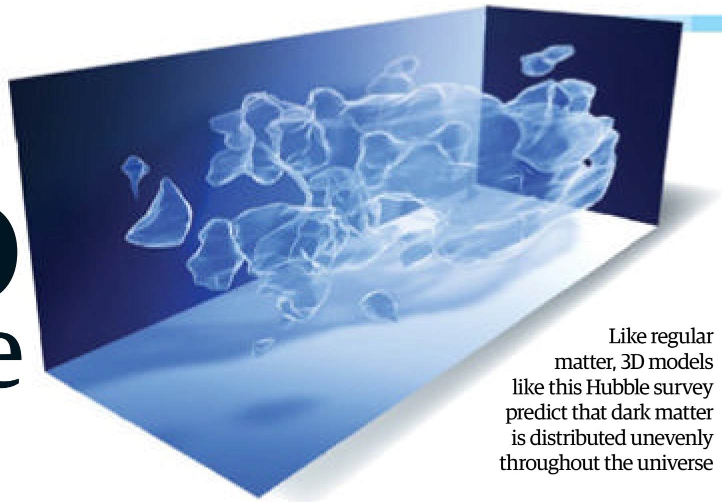
There is also the Big Rip theory, where the expansion of the universe would continue to accelerate at such a rate that all the matter would be forcibly ripped apart at the seams.

However, the most popular of all current theories is the Big Freeze, which simply dictates that the expansion – and cooling – of the universe will continue unabated until everything in it reaches 'absolute zero'. At this point the universe would cease to move and would become stable, possibly existing forever.

Either that, or our universe could actually be a multiverse and every other possible end to the universe could quite feasibly be happening right now. Since a multiverse of infinite 'verses' would require infinite space and energy, the multiverse would never cease to exist.



96% of universe is missing



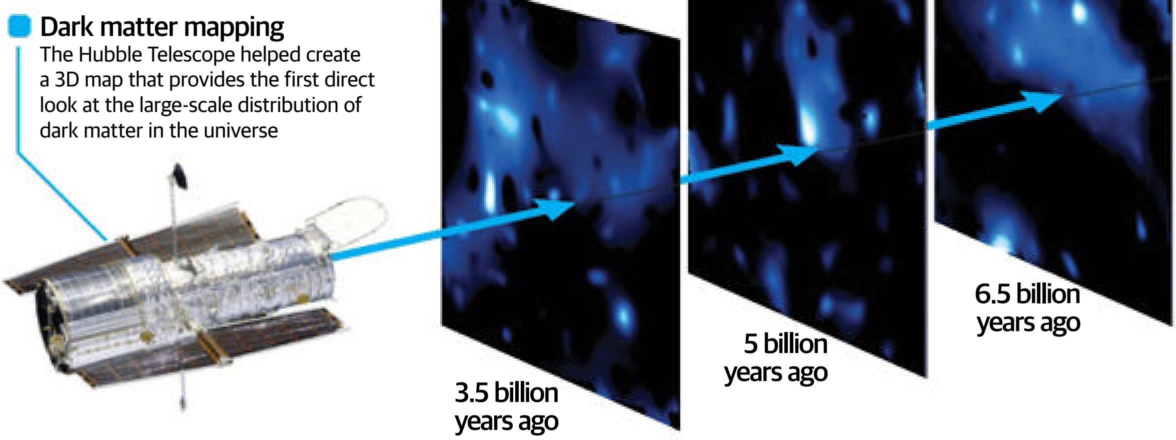
Like regular matter, 3D models like this Hubble survey predict that dark matter is distributed unevenly throughout the universe

The chilling discovery came to light in the Nineties when astronomers realised the universe's expansion was accelerating instead of slowing, as they'd predicted.

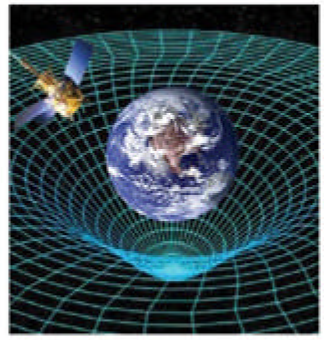
So little is currently known about the mystery, the term 'dark matter' effectively exists as a placeholder – a means to explain an unfathomable problem in a barely more comprehensible way. Thanks to more recent discoveries we do at least have a rough idea of where dark matter resides.

The globular image above depicts the distribution of dark matter across the universe. The COSMOS survey, a Hubble project studying the relationship between large scale structure (LSS) in the universe and dark matter, as well as the formation of galaxies – has offered the most compelling evidence yet that known matter tends to cohabit the same space as the densest concentrations of dark matter. Just don't ask anyone what it is...

Finding dark matter

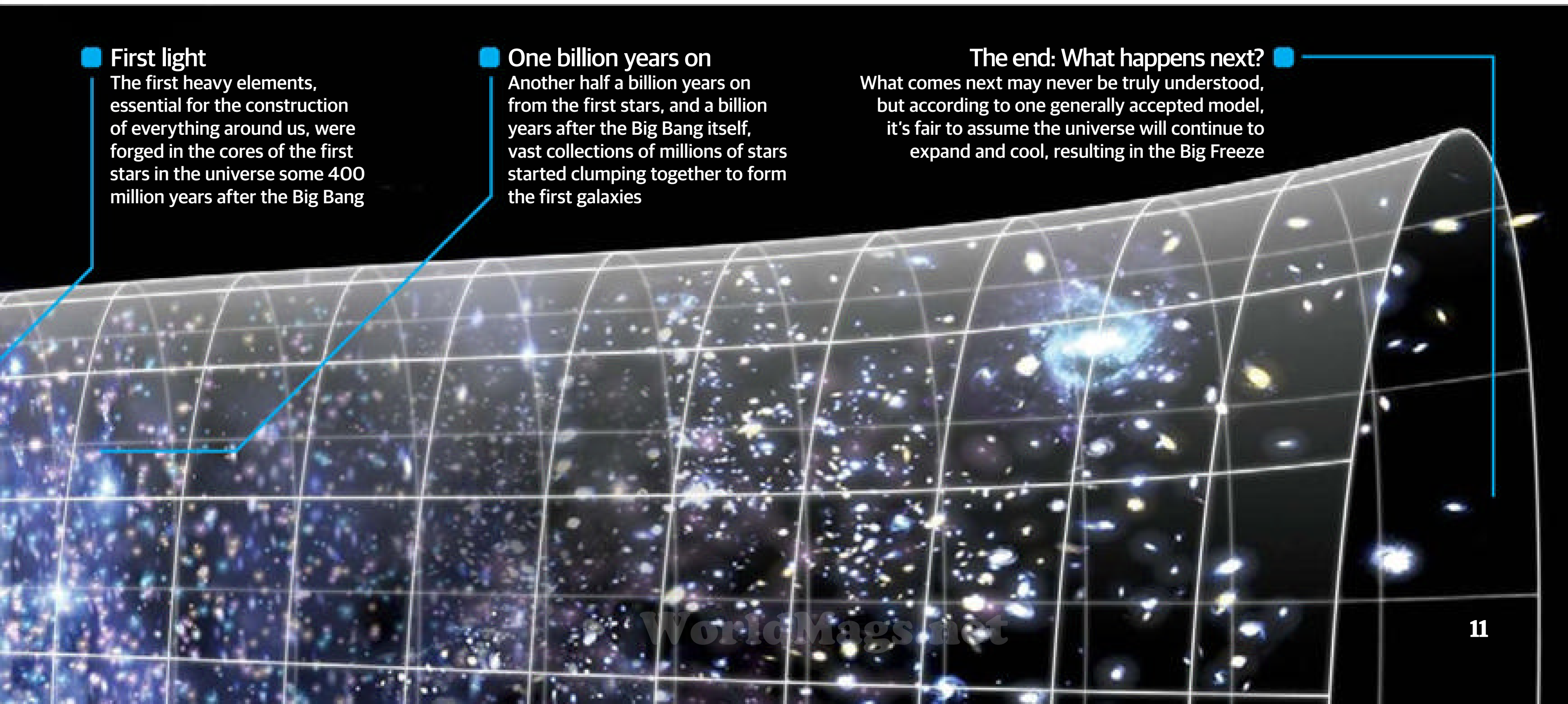


Gravity cannot be explained



Gravity is a mind-boggling conundrum. Despite being able to predict its effect with enough scientific accuracy to chart the locations of celestial bodies millions of years into the future, we haven't yet entirely grasped what makes it work.

We know that gravity operates at the speed of light and attracts clumps of matter with a force directly proportional to their mass and is unlike the other three forces of nature, because it has a fundamental relationship with time and space. What we don't know is what particles are actually responsible for creating the force of gravity. Researchers at particle accelerators on Earth like the Large Hadron Collider near Geneva, Switzerland are hoping to find the answer soon.



Mining asteroids

James Cameron and Google's Eric Schmidt and Larry Page establish the first asteroid-mining company

If successful, Planetary Resources could send robotic mining vehicles to asteroids

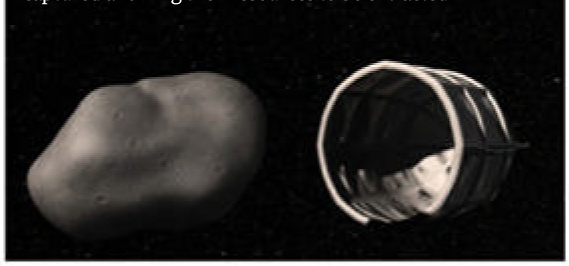
It might sound and look like something out of a sci-fi film, but asteroid mining is very much a reality, and one that could greatly benefit humanity. For decades it has been nothing but a pipe dream and, until recently, nobody had been able to devise a clear plan for long-term mining of an asteroid.

That all changed when a new company called Planetary Resources, Inc outlined a clear goal in early 2012 to mine near-Earth asteroids for valuable minerals. Set up by some familiar and rich names, including James Cameron and Google's Eric Schmidt and Larry Page, the company aims to supplement the Earth's natural resources by developing and deploying robotic asteroid-mining vehicles.

Right now, Planetary Resources is still in its very early planning stages, attempting to identify the key technologies that will allow it to produce the necessary machinery to forge these large mining droids. However, the ultimate aim – and one in which its backers readily accept is still a number of decades away – is to survey numerous asteroids for their mineral and water content, before dispatching automated miners to harvest them. Up to five orbital telescopes are expected to be launched by 2014 to begin the survey.

> "The aim is to survey asteroids for mineral and water content before dispatching automated miners"

Small, water-rich, near-Earth asteroids could be captured allowing their resources to be extracted



Indeed, the existence of Planetary Resources is fascinating because it is in it for the long haul, creating a completely conceivable roadmap to asset extraction. If successful, the endeavour could prove very profitable for the company, with studies indicating that most asteroids are rich in minerals such as iron, nickel and titanium – which are in restrictive supply on Earth. If these elements could be extracted and processed it would prove invaluable for future industry.

What is most fascinating, though, is that in its mission to mine asteroids, Planetary Resources could actually provide a viable base from which humans could expand into the Solar System. If water, oxygen and construction materials can be acquired from off-planet sources, then the speed and quantity of any planned colonisation project would be dramatically increased.

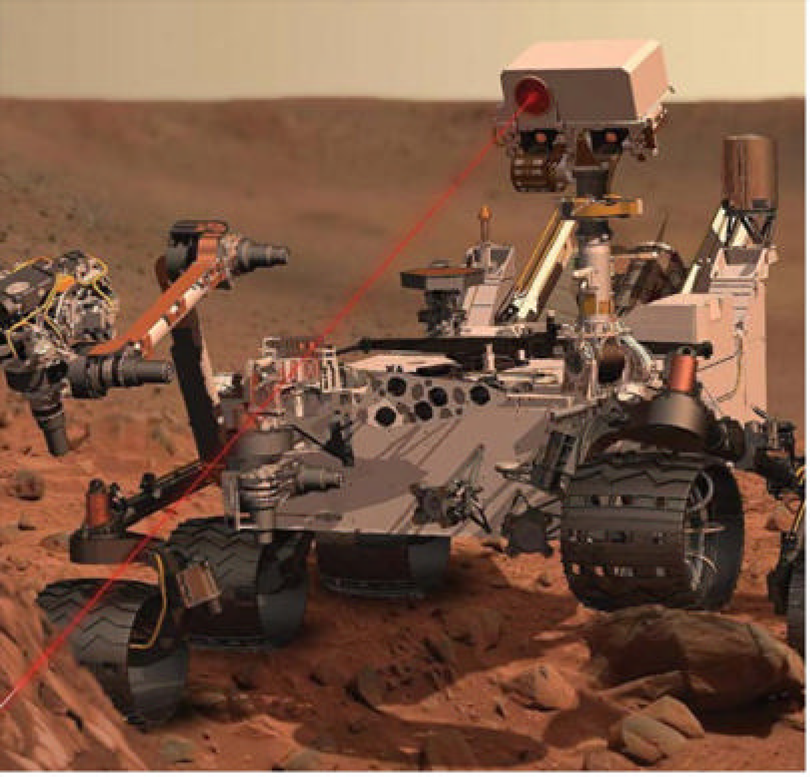
Who's involved?

Eric Schmidt
Schmidt is the executive chairman of Google. He is also a celebrated software engineer.

Larry Page
Page is the CEO of Google and also its co-founder. He specialises in computer science.

James Cameron
Director of *Aliens* and *Terminator 2*, Cameron also helped build the Deepsea Challenger.

Peter Diamandis
Diamandis is a space-flight entrepreneur and expert in designing space vehicles.

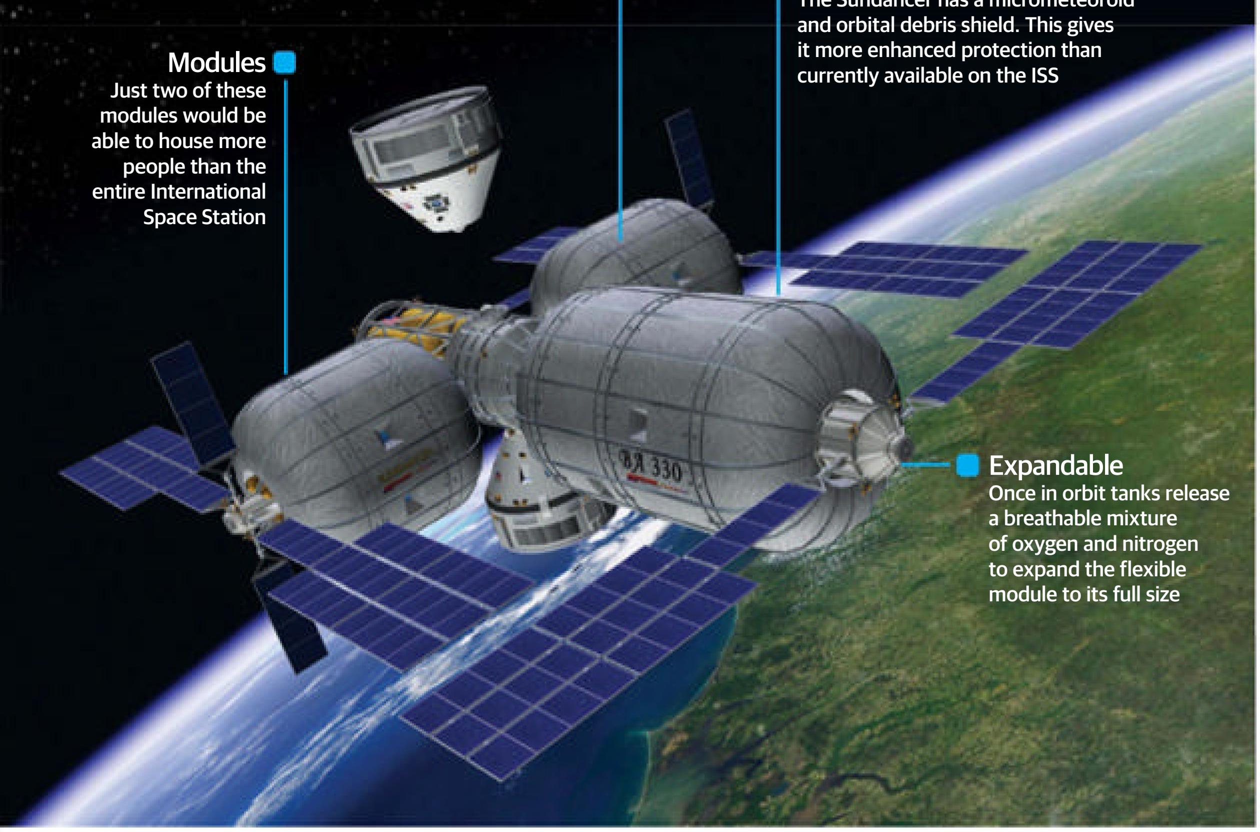


Firing lasers on Mars

The Science Laboratory mission to land the Curiosity rover on Mars blasted off on 26 November 2011 and is a simply phenomenal project. Once it has parachuted down to Mars, the state-of-the-art vehicle has only one purpose – to help assess the habitability of the Red Planet. It will do this by performing various tests in its onboard laboratory, including large-scale chemical analysis of its rocky surface, using a ChemCam laser to vapourise pieces of the terrain for more effective study.

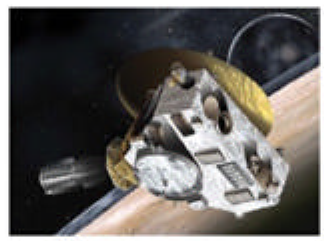
Inflatable space stations

Bigelow Aerospace's inflatable Sundancer space complex is a glimpse into the future of commercial space habitation, laying the groundwork for the BA 330, the first model of its kind to go into production. Launching in a compacted state the Sundancer will expand once it enters orbit. It has been designed with space tourism in mind and, if all goes to plan, could be offering stay-overs within the next decade.



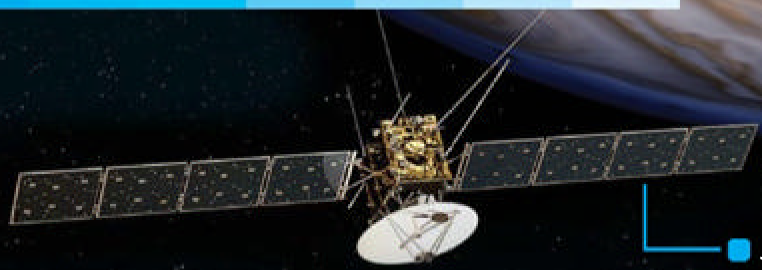
Book a flight to the ISS

SpaceX's Dragon spacecraft is exciting for all the right reasons. As discussed earlier (see page 12) it has already begun cargo missions to the International Space Station, and in the next few years it is set to begin manned expeditions to space, the first private spacecraft ever to do so. It has already received funding from NASA under the Commercial Crew Development programme, and by 2015 at the earliest it is expected to start ferrying up to seven astronauts on each flight to Earth orbit.



First visit to Pluto

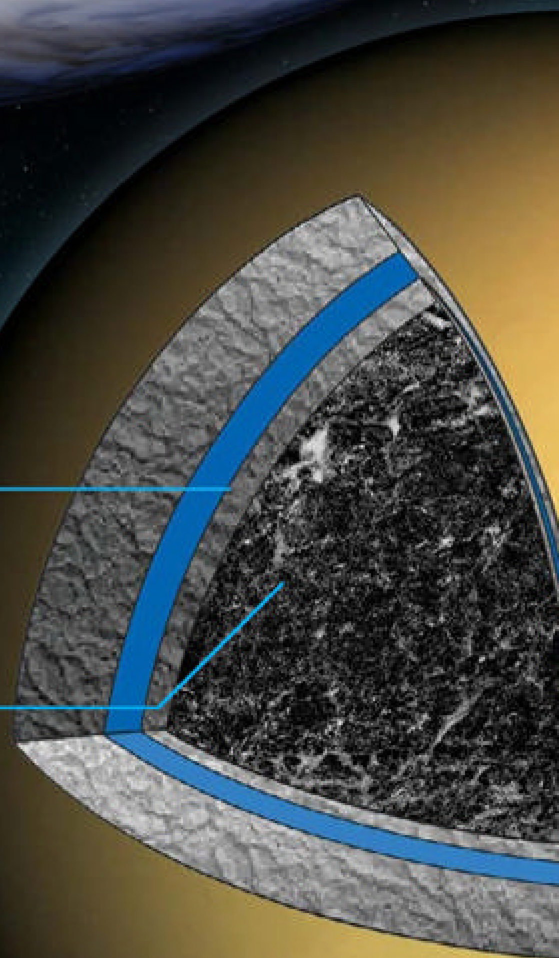
Currently en route to the dwarf planet Pluto, NASA's New Horizons spacecraft holds the record for the highest-velocity ejection speed from Earth's atmosphere of any human-made object. It was fired directly into an Earth-and-solar escape trajectory with the equivalent speed of 58,536 kilometres per hour (36,373 miles per hour)! Upon reaching Pluto in 2015 it will complete the first-ever flybys of the super-cold planet and its moons – Charon, Nix and Hydra – analysing them and their environment with its seven on-board sensors.



JUICE
The possibility of finding alien life on Ganymede is the main focus of JUICE's mission to Jupiter

Discovering life on Jupiter

The JUICE spacecraft (Jupiter Icy Moon Explorer) – is arguably the most exciting development yet in the search for alien life. The European Space Agency spacecraft, which was selected above a host of rivals for the crucial mission, is due to head to the Jupiter system in 2022 in search of new life forms. Launching on the back of the extremely powerful Ariane 5 rocket, JUICE will engage its solar-powered electric engines and make the long-haul, eight-year flight to Jupiter. Upon arriving, JUICE will analyse the planet, as well as its icy moons Europa, Callisto and – most importantly – Ganymede. Ganymede will be the focus of its 1.4GB daily data downlink as reports indicate that it contains a subsurface ocean. If this is true, then that ocean could be the location of our very first contact with an alien organism.



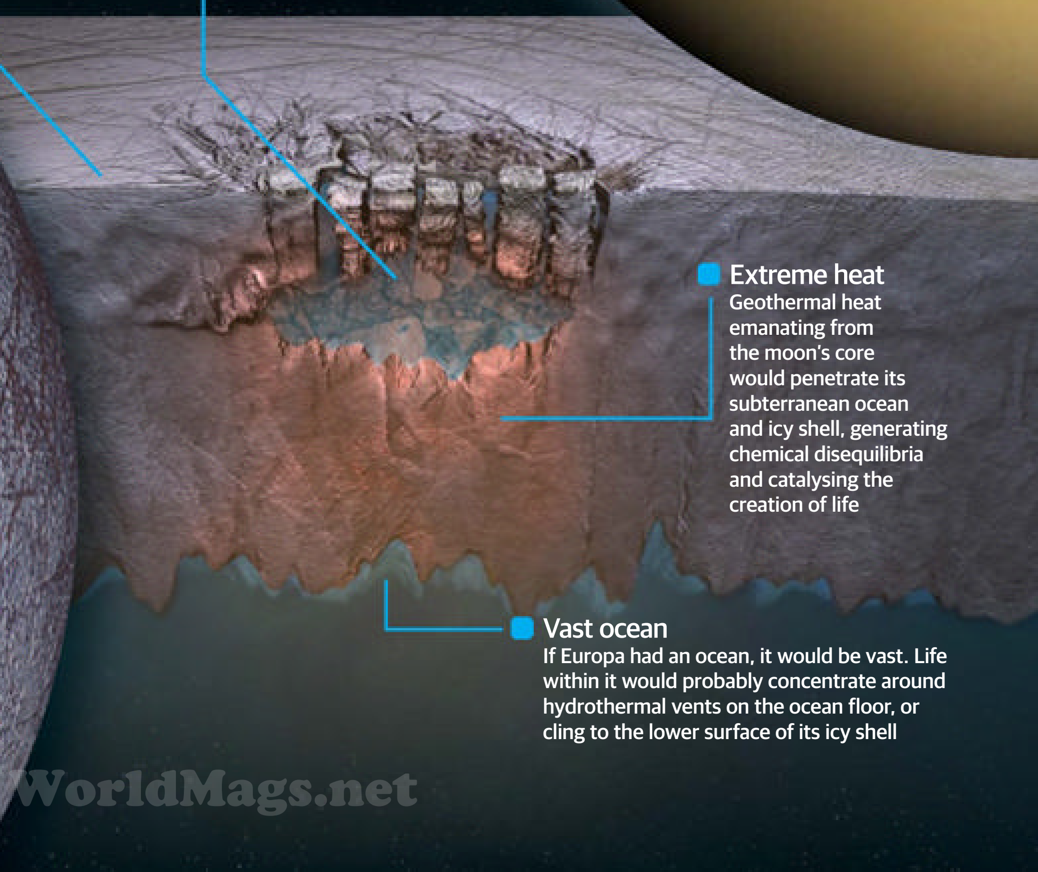
Life-bearing ocean?
There is a strong chance that Titan has a life-bearing underground ocean of water and liquid ammonia roughly 200km (124 miles) beneath its surface

Silicate core
Reports indicate that Titan has a silicate core and that its interior may still be hot, with a layer of magma-like material composed of water and ammonia generating heat

Underground oceans of Europa

While primarily being sent to search for alien life on Jupiter's moon Ganymede, the JUICE spacecraft will also be deployed to Europa. The reason? Scientists at NASA and the ESA believe it could also harbour life. Indeed every report beamed back to Earth to date has indicated that due to the moon's smooth and youthful surface, there is an excellent possibility that it covers a vast subterranean ocean.

If there is an ocean under Europa, then – as demonstrated in missions down to the bottom of Earth's deepest and coldest oceans, where microbial life is abundant – there is a possibility that some form of life could exist as deep hydrothermal vents emanating up from the moon's core could inject geothermal energy into the waters, providing the catalyst to the creation of life.



Young crust
Europa's surface is largely crater-free. This leads scientists to believe that it is relatively young and could harbour underground oceans and lakes

Underground lakes
In addition to a vast underground ocean, studies have shown that huge liquid lakes could also exist, entirely encased within Europa's icy shell

Extreme heat
Geothermal heat emanating from the moon's core would penetrate its subterranean ocean and icy shell, generating chemical disequilibria and catalysing the creation of life

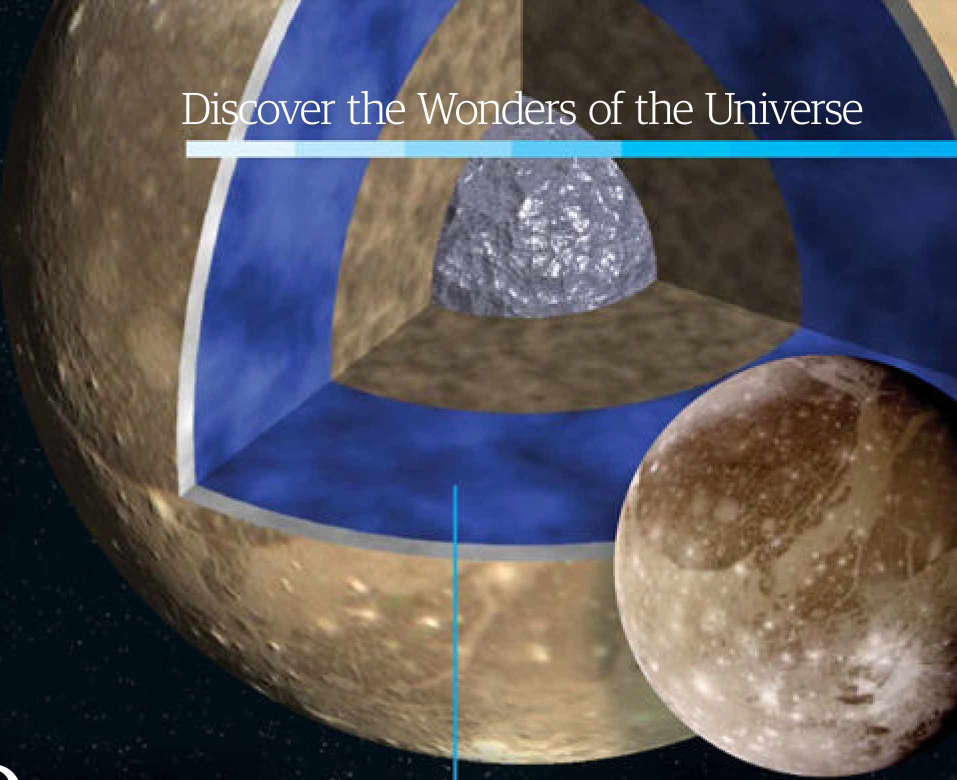
Vast ocean
If Europa had an ocean, it would be vast. Life within it would probably concentrate around hydrothermal vents on the ocean floor, or cling to the lower surface of its icy shell

Earth-like surface
Titan's surface is Earth-like, with rivers and lakes of liquid ethane and/or methane potentially providing habitats for non-water-based life forms

Atmosphere
Much like its surface, Titan's atmosphere is also very Earth-like. It is dense, chemically active and is privy to weather such as cloud formations and rain

Titan's Earth-like climate

Saturn's moon Titan is incredibly interesting because it has a dense nitrogen-rich atmosphere and a climate similar to that on Earth, with wind, rain and clouds a frequent occurrence. Indeed, its surface even has similar features, too, such as sand dunes, rivers, lakes and seas – although the latter's 'water' is most likely liquid methane and ethane. As such, it is thought by scientists to potentially be a habitat in which microbial extraterrestrial life could survive, or at the very least, act as a rich prebiotic environment for their future creation.



Going deeper
Ganymede has a cold rigid ice crust, an outer warm ice mantle, an inner silicate mantle and a metallic core

Oxygen on Ganymede

Reports indicate that oxygen may exist within the atmosphere of Jupiter's Ganymede moon. The oxygen is created when water ice on the moon's surface is split into hydrogen and oxygen by impacting radiation waves, with the hydrogen then proceeding to be lost from the atmosphere quicker than the oxygen due to its low atomic mass. This process leaves a thin layer that includes oxygen, oxygen gas and ozone. Importantly, however, the presence of oxygen is not direct evidence that there could be life on Ganymede, rather just an extra layer of chemical complexity in which life could, theoretically, be generated. However, the oxygen concentrations on Ganymede are roughly equivalent to those found on Mars, a planet on which scientists believe life could have existed at one time.

Life in the methane lakes?

One of the best chances of finding life on Titan is within its numerous, large methane lakes. These lakes, which litter the moon's surface, could act as our water-based ones do on Earth.

Critically, however, for this to be possible it would require the alien organism to intake hydrogen rather than oxygen, react it with acetylene instead of glucose and produce methane instead of carbon dioxide.

While sounding far-fetched, it becomes more of a reality when you consider that there are various methanogens (methane-producing microorganisms) on Earth that obtain their energy by reacting hydrogen with carbon dioxide in a very similar way.

Bodies of liquid ethane and methane have been detected on Titan by the Cassini-Huygens space probe

Discovering new Earths

Scientists are busy in their search for new, Earth-like planets outside of our Solar System and new advances in technology may help us find one soon

Planet hunting is a new and exciting area of astronomy barely two decades old that, thanks to missions such as NASA's Kepler telescope, is revealing more and more data about intriguing new worlds outside of our Solar System, known as extrasolar planets or exoplanets. Only in the last 20 years has sufficient technology been available to allow us to categorically prove the existence of these planets. While we're still some way off seeing detailed imagery of direct exoplanet observations, projects like NASA's James Webb Space Telescope and the European Extremely Large Telescope (E-ELT) will bring Earth-size exoplanets into view and even study the composition of their atmospheres.

The number of bizarre and familiar new worlds just waiting to be discovered is staggering, if estimates prove to be accurate. In our Milky Way alone there could be hundreds of billions of planets, and so far we've found just a few thousand. The ultimate goal for planet hunting is to find an Earth-analogous planet that could help ascertain whether life could potentially grab a foothold outside of our Solar System.

The key to discovering an Earth-like planet is to find those that are within the habitable or 'Goldilocks' zone of a star, the area within which the conditions are thought to be 'just right' for water to form. Kepler-22b was the first such planet to be found and, while it is now thought to have a thick atmosphere that may be inhospitable to life, it was very influential in helping to spur the discovery of new Earth-like planets. One example of these was Gliese 581 g, a planet no more than

> "Projects like the James Webb Telescope will bring Earth-sized exoplanets into view"

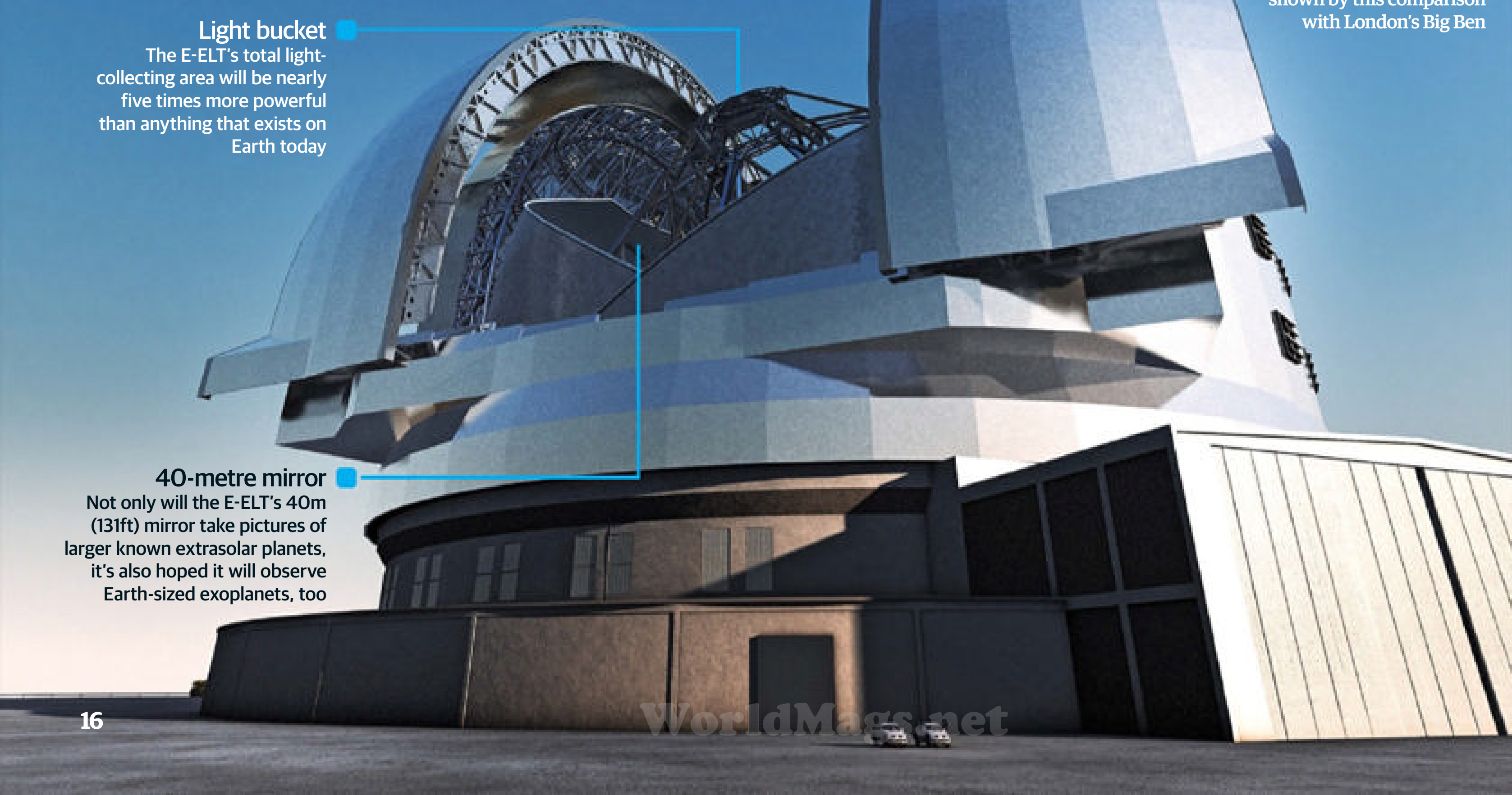
The search for extraterrestials

Often described as the world's biggest eye on the sky, the European Extremely Large Telescope (E-ELT) is one of a new breed of scopes that will be capable of bringing extrasolar planets, the universe's first objects and black holes into focus.

The E-ELT project, first put into motion in 2005 and due to be operational in 2020, will be based at the world famous Cerro Armazones observatory in Chile.

Its primary light-gathering mirror will measure 39.3 metres (128.9 feet) in diameter and will be constructed from no less than 798 hexagonally shaped mirror segments each measuring 1.4 metres (4.5 feet) across.

The E-ELT is huge, as shown by this comparison with London's Big Ben

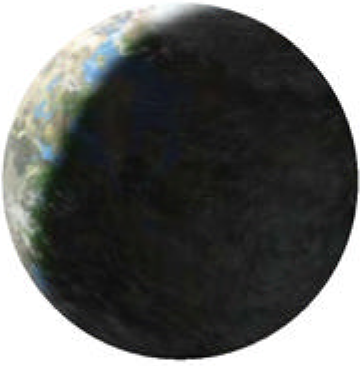


four times the mass of Earth sitting right in the middle of the habitable zone of its host red dwarf star. While a year on this planet is only 37 days, observations suggest that Gliese 581 g may be a suitable planet on which life could reside.

Another potentially life-harbouring planet is HD 85512 b, a so-called 'Super-Earth', like Gliese 581 g, with a mass at least 3.6 times that of our home planet but with a temperature that could potentially allow for the existence of liquid water, which is thought to be one of the key components for life to form or survive. Over the next few years, as our methods of finding and characterising exoplanets become more and more sophisticated, it's likely that more Earth-like planets like these will be discovered all over the Milky Way.

3 amazing Earth-like planets

m = mass of the Earth
r = radius of the Earth



Gliese 581 g

Distance from Earth: 20 light years
Star: Gliese 581 **Constellation:** Libra
Discovered: 2010
Mass: 3.7m **Radius:** 1.3r
Temperature: -20°C

HD 85512 b

Distance from Earth: 36 light years
Star: HD 85512 **Constellation:** Vela
Discovered: 2011
Mass: 3.6m **Radius:** Unknown
Temperature: 25°C

Kepler-22b

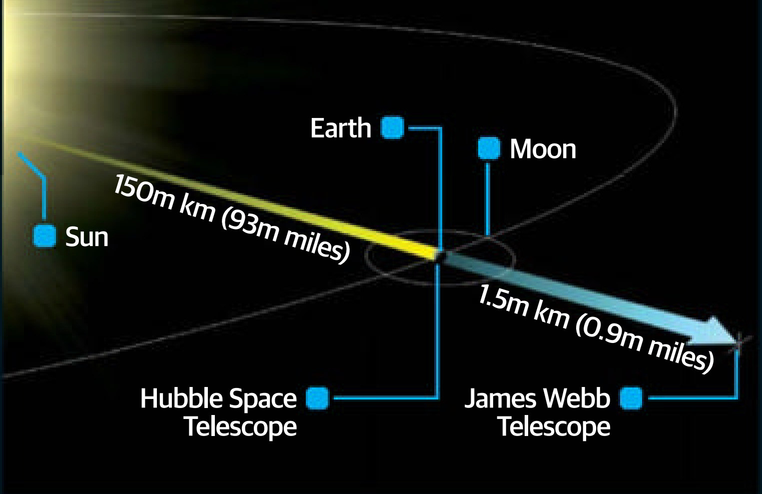
Distance from Earth: 620 light years
Star: Kepler-22 **Constellation:** Cygnus
Discovered: 2009
Mass: Unknown **Radius:** 2.4r
Temperature: -11.15°C

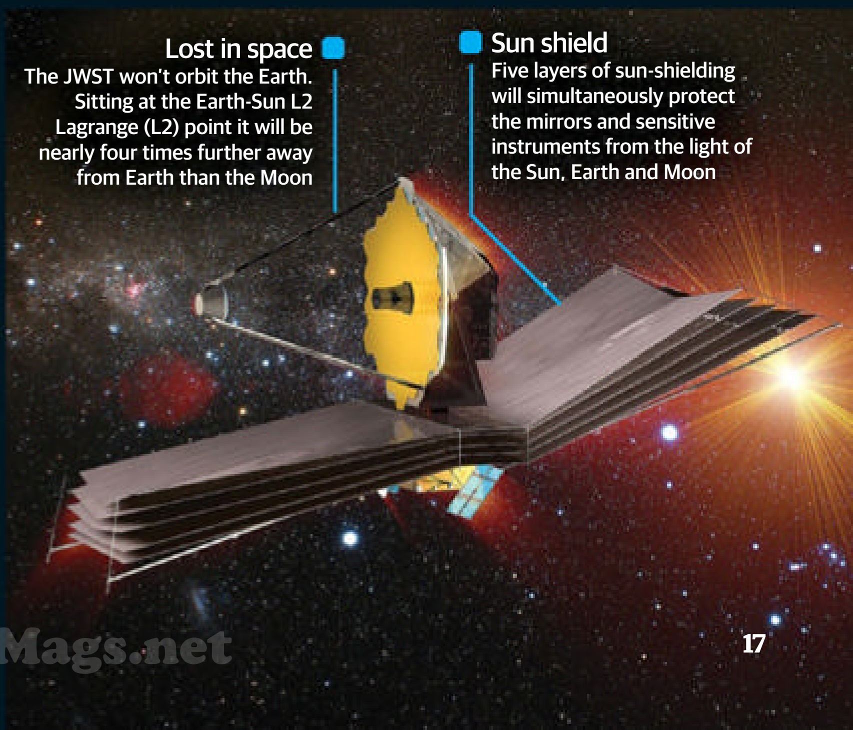
Most spectacular telescope ever

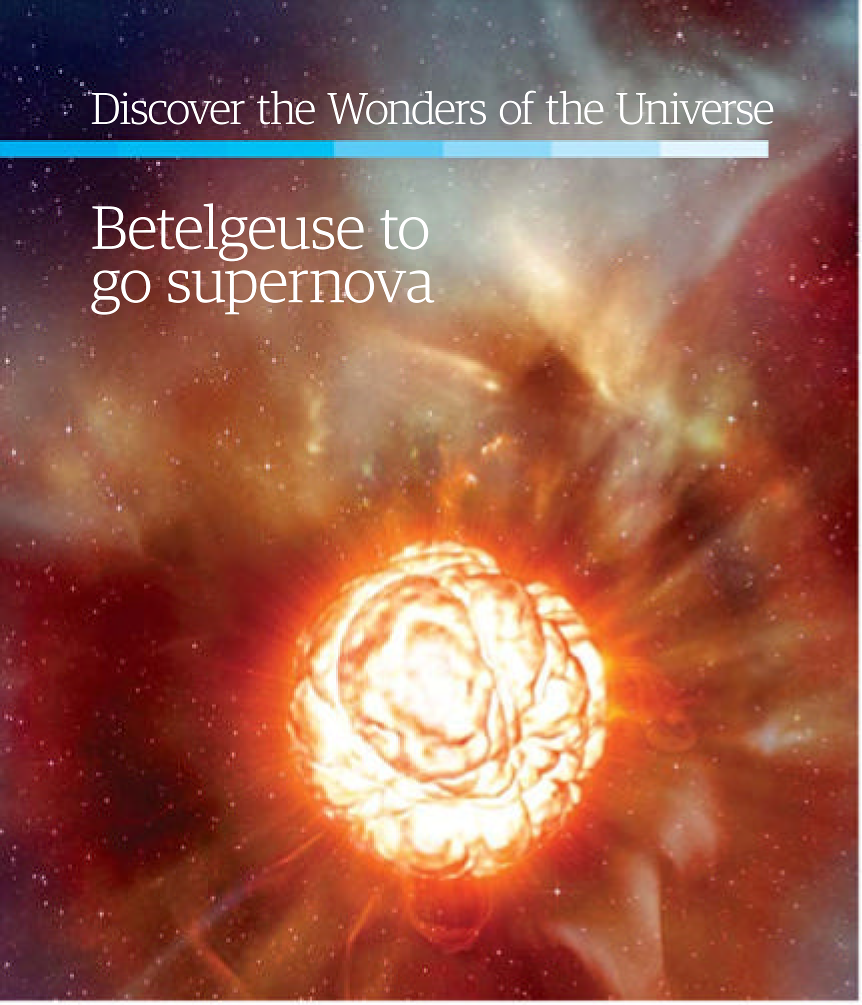
Named after the NASA administrator who created the Apollo space programme, the James Webb Space Telescope (JWST) is set to blast off to Earth orbit in 2018. Although often described as the successor to Hubble, the JWST will be a very different beast. First, it's much bigger. While Hubble was 13 metres (42 feet), JWST's sun shield alone is nearly twice the length at 22 metres (72 feet). The diameter of the primary mirror puts Hubble's 2.5-metre (8.2-foot) offering in the shade, too - at 6.5 metres (21.3 feet) it has a total light-collecting area of nearly 15 square metres (161.4 square feet).

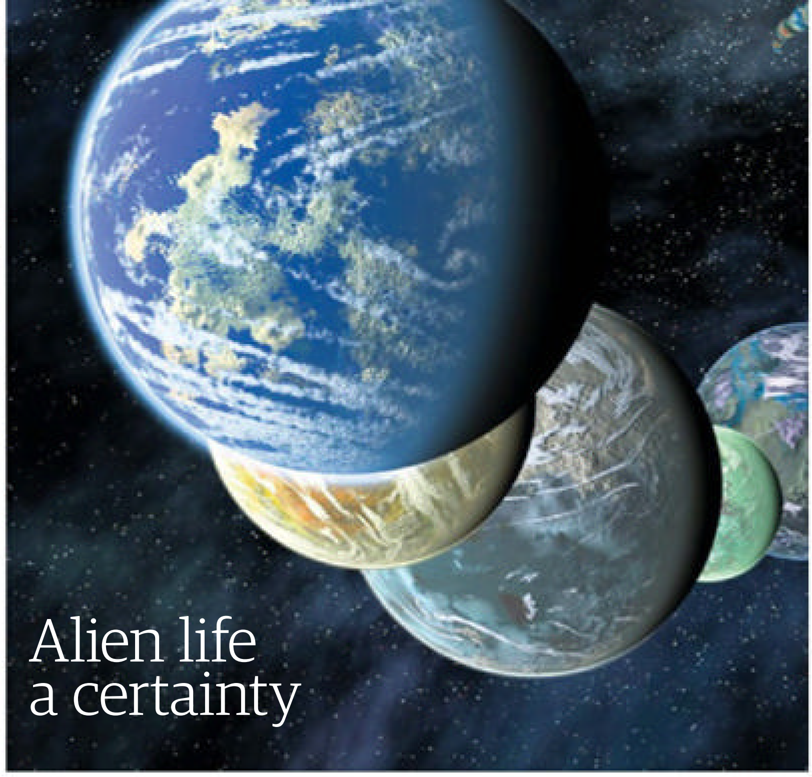
JWST is also designed to do its work in the infrared end of the spectrum, as opposed to Hubble's optical (and ultraviolet) wavelengths. This will let us see through the dust that clogs our view to the centre of our galaxy to offer us a glimpse of the supermassive black hole that resides there and investigate accretion discs of young stars so we can see how solar systems - and planets - form.

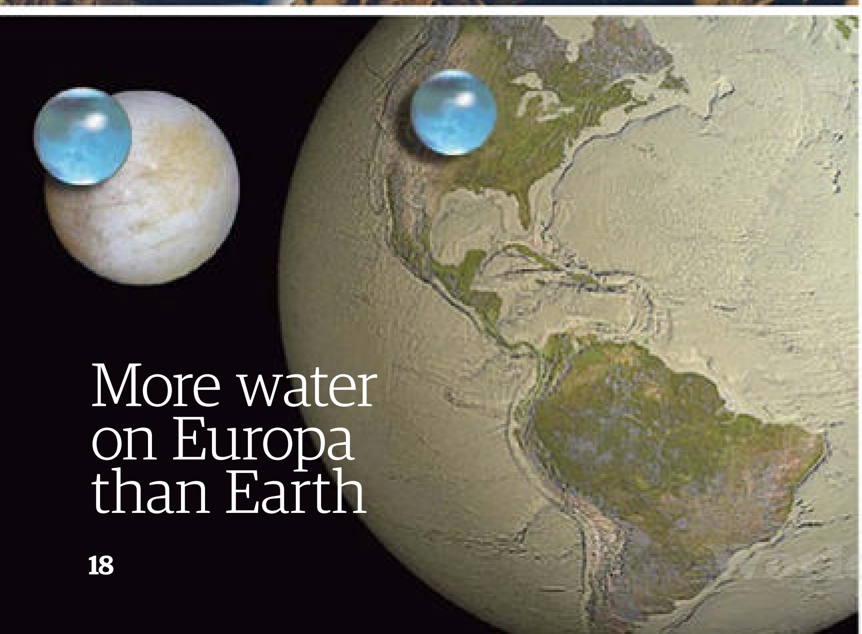
Where will the JWST be?











10 fascinating space facts you need to know

Meteorite-sized nuggets of fantastic space info that will blow your mind

Betelgeuse could go supernova
The red super giant star Betelgeuse is due to die at any moment. The event could see the star reach a comparable brightness to that of a full moon.

The Space Shuttle is no more
NASA's youngest Space Shuttle, Endeavour, having flown its last mission in May 2011 is now on display at the California Science Center in LA.

There's more water on Europa than Earth
Data acquired by NASA's Galileo spacecraft suggests there is up to three times more water under the surface of Saturn's moon Europa than on Earth.

The chance of extraterrestrial life is 100 per cent
That's according to the Drake equation, a mathematical equation used to estimate the number of extraterrestrial civilisations in our Milky Way galaxy. Mr Drake's own estimate came to over 10,000 alien civilisations.

Virgin Galactic set to take tourists into space
From late 2012 Spaceport America began hosting the first-ever space tourism flights courtesy of Virgin Galactic. It has 400 accepted reservations already on the books.

A soup can's worth of a neutron star would weigh more than the Moon itself
A neutron star is formed when a star of between eight and ten solar masses dies. A teaspoon of it would weigh more than everyone on Earth, while a soup can would weigh more than the Moon.

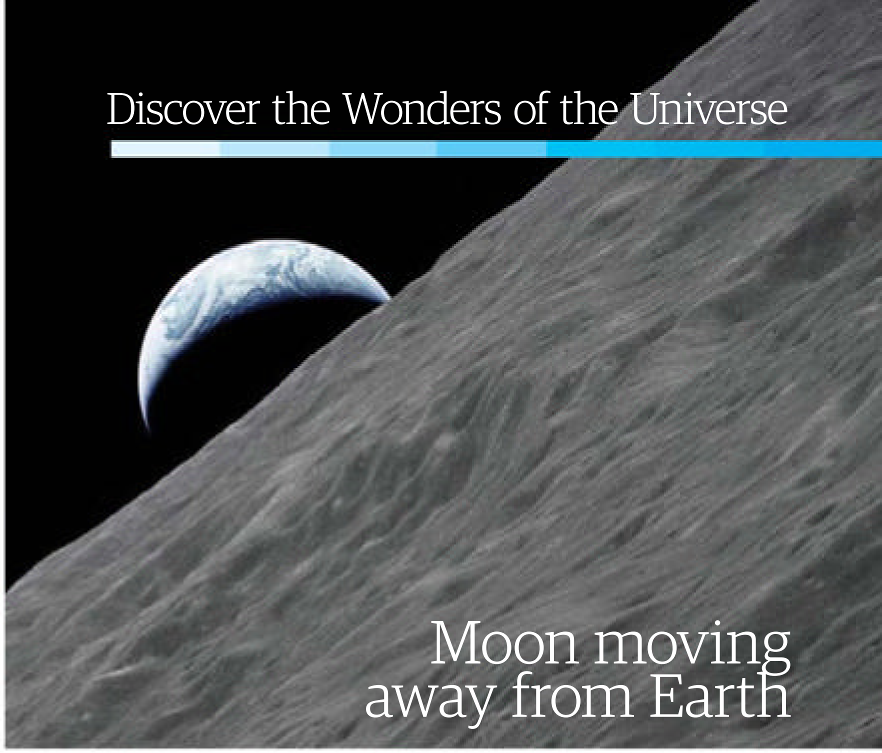
World's biggest telescope array set for completion
In 2012 the Atacama Large Millimeter/sub-millimeter Array (ALMA) in Chile was completed and consist of 66 twelve-metre and seven-metre diameter radio telescopes. It will be the biggest until the completion of the Square Kilometre Array in 2019.

The Moon is moving away
The Moon has been moving 38 millimetres away from the Earth every year since its formation.

Humans are going to Mars
NASA and Lockheed Martin hope to send humans to Mars by 2035 with the jointly created Orion spacecraft.

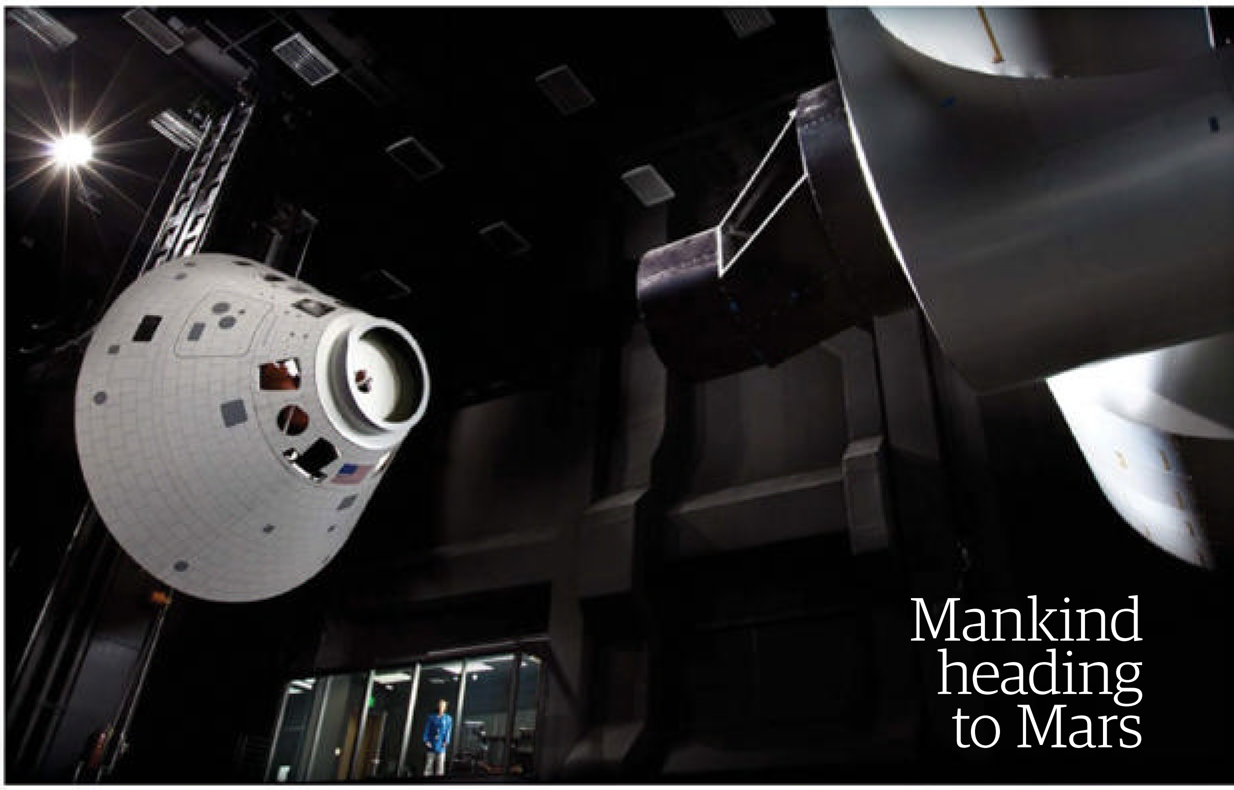
The Sun loses a billion kilograms every second
The sun burns through a billion kilograms of its own mass each second. That works out at about three Empire State Buildings every second!

Space tourism is go



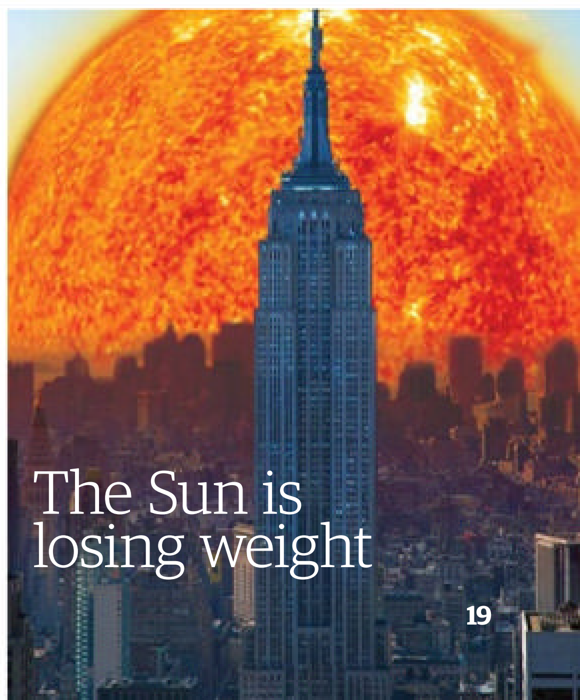
Moon moving away from Earth

A tin heavier than the Moon



Mankind heading to Mars

Huge telescope array finished in 2012



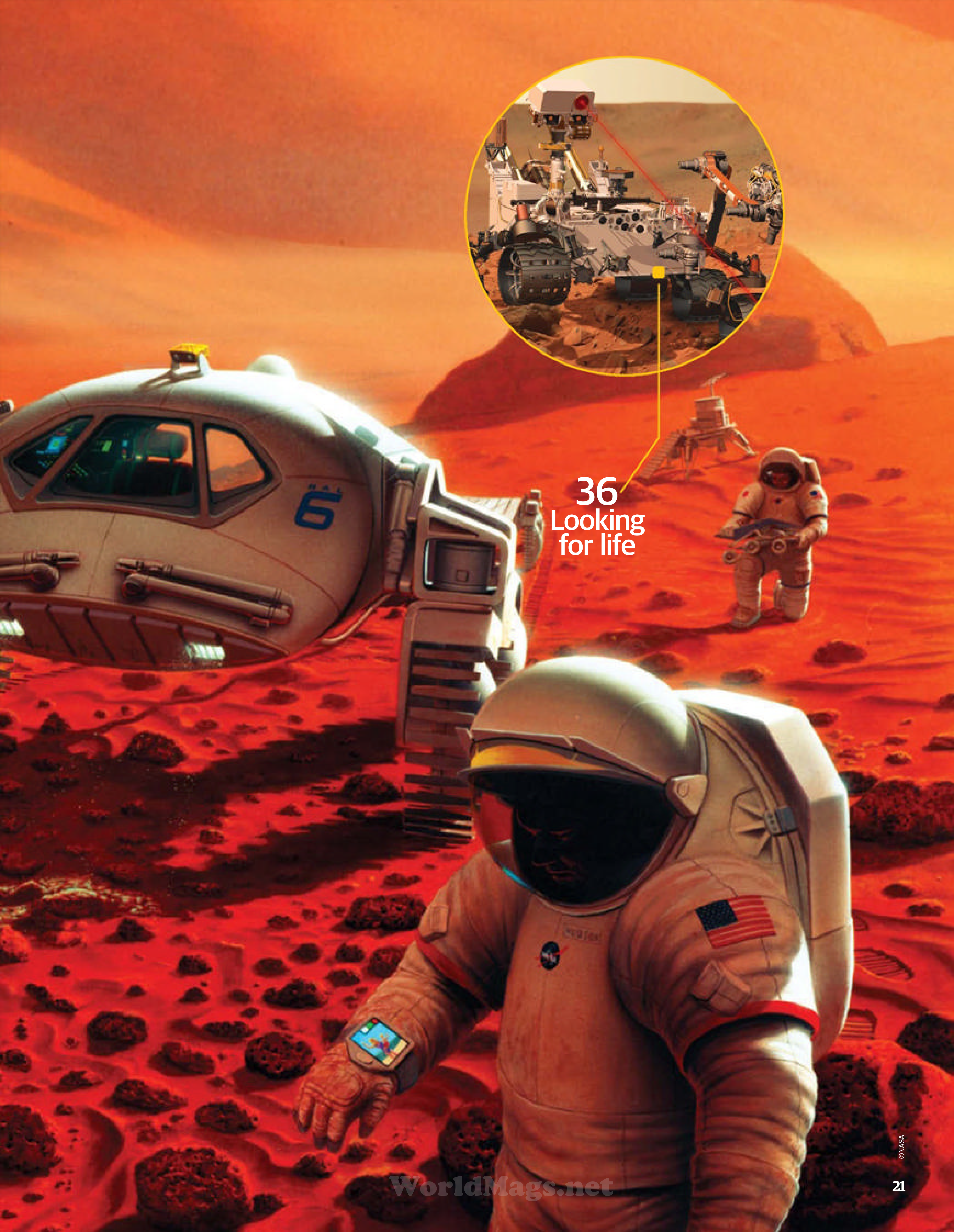
The Sun is losing weight

Explore the Galaxies

Discover where mankind has been and where it will go

32 Lunar Lander

"Billionaires can book their flight around the Moon for as early as 2018"



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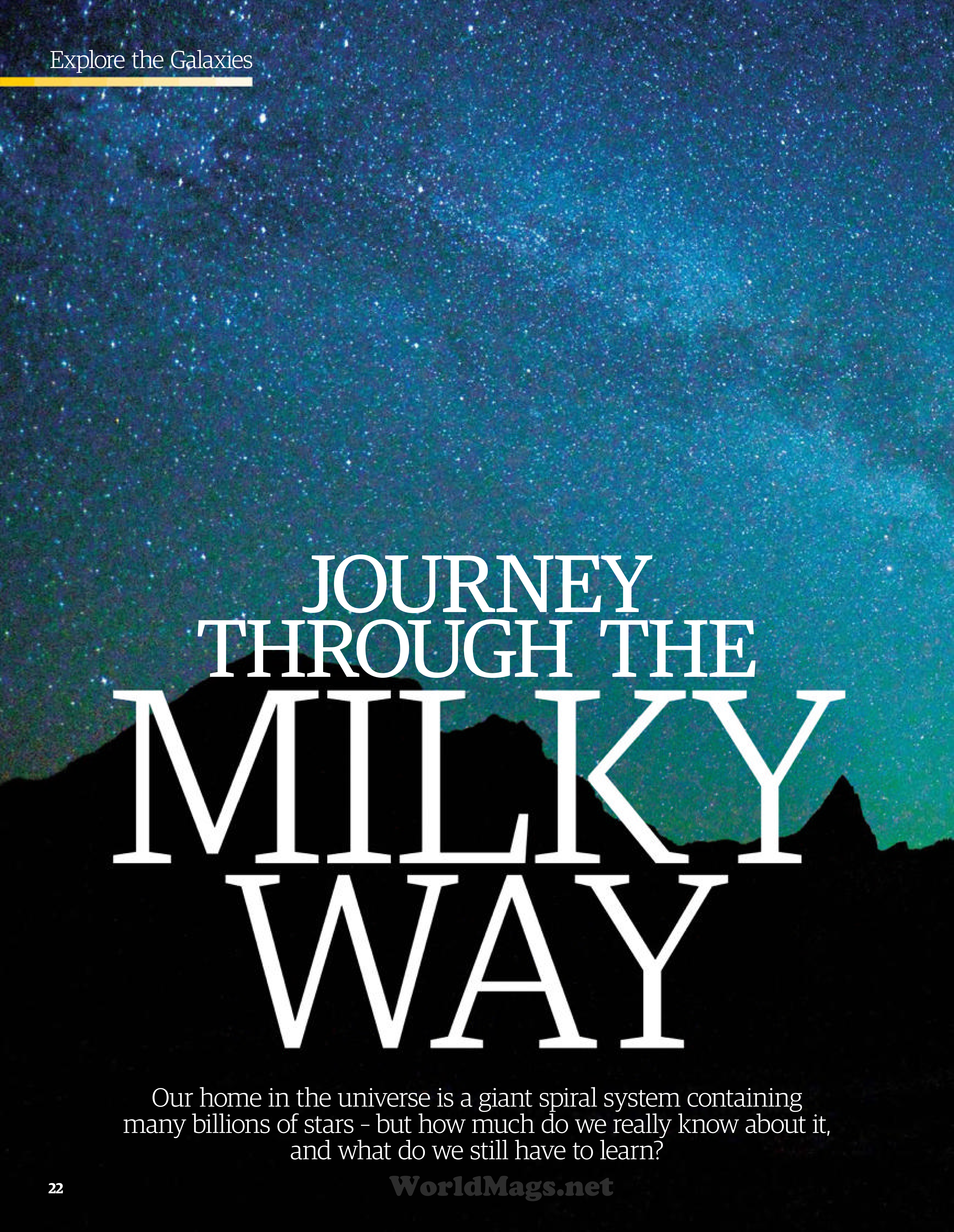


JOURNEY THROUGH THE MILKY WAY

Our home in the universe is a giant spiral system containing many billions of stars – but how much do we really know about it, and what do we still have to learn?

Look up at the sky on a dark, clear night and you can't miss the Milky Way – a broad swathe of pale light winding its way around the sky among many of the brightest individual stars. Ancient astronomers saw it as a stream of milk spilt across the sky by the goddess Hera when she suckled the hero Hercules, but today we know the Milky Way is something very different – an enormous disc of stars some 100,000 light years across, containing (at the latest estimate) around 200 billion individual stars.

Unsurprisingly, then, our Solar System is an insignificant speck within the overall scale of the Milky Way – all the planets and other large bodies orbiting the Sun are confined to a region just a few light *hours* across. In our part of the galaxy, stars are spaced far enough apart that even our nearest stellar neighbours appear as mere specks of light. The closest of all, the triple star Alpha Centauri, is still around 4.3 light years away.

The overall shape of our galaxy has been likened to two fried eggs placed back to back, with a broad, flat disc of scattered stars, gas and dust surrounding a bulging central hub where stars are more densely packed together. Our Solar System and its neighbours lie in a relatively sedate, outlying region of the Milky Way, about halfway between the centre and the edge. With a little understanding of the Milky Way's structure, the band of light across the night sky is easy to understand: when we look across the plane of the Milky Way's disc, we see far more stars lying in any given direction and these effectively merge together into a generalised glow. On the other hand, when we look 'up' or 'down', out of the galactic plane, we are staring into largely empty intergalactic space, with only relatively nearby stars in our part of the disc to get in the way.

In 1785, astronomer William Herschel made the first attempt to map the Milky Way in detail, by exhaustively counting the number of stars he could see in different directions across the sky. He proved beyond doubt that the Milky Way was a flattened plane, but unfortunately misunderstood its shape because he believed that our own Solar System was near the centre of the galaxy.

In the late-Twenties, Jan Oort set out to study the movement of individual stars in different parts of the sky. He soon confirmed that the Milky Way is rotating, showed that its centre lies in the direction of the constellation Sagittarius, and also proved that galaxies do not rotate like solid bodies – instead the stars closer to the galactic hub move more quickly along their orbits, while stars further out circle more slowly – a phenomenon known as 'differential rotation'. The Sun, for instance, takes around 200 million years to complete a single orbit. Later measurements in different parts of the disc showed that orbital speeds do not change as dramatically as

they should do if they are governed by the mass of the Milky Way's visible matter alone – evidence that our galaxy contains large amounts of transparent but weighty 'dark matter'.

Even today, our understanding of our galaxy is constantly evolving thanks to new theories and new observing technologies. Radio, infrared, ultraviolet and X-ray observations can pierce the dense clouds of stars and dust that obscure large parts of the Milky Way in visible light, while new analytical techniques allow astronomers to learn far more from the stars we can observe. So what is our current understanding of this enormous stellar system?

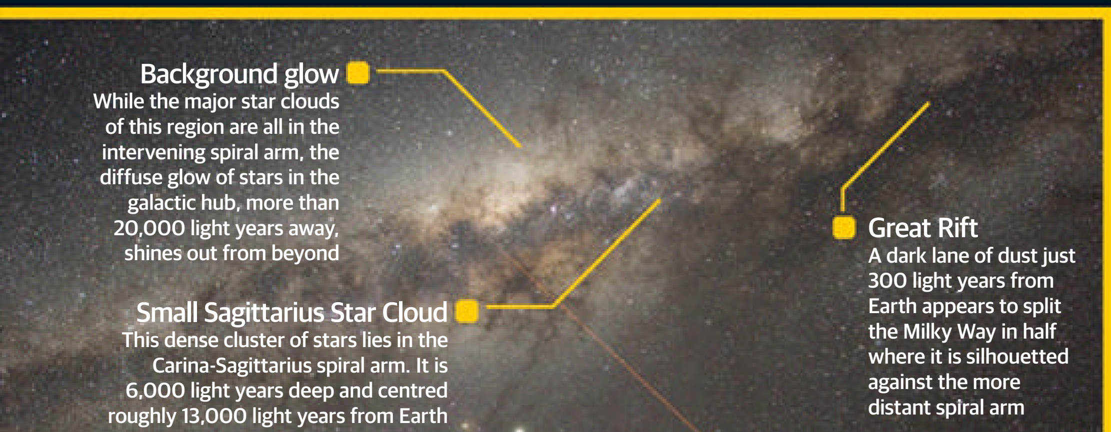
The Milky Way is a barred spiral galaxy, around 100,000 light years across and with a disc roughly 1,000 light years thick in most places. Its central hub is formed by a densely packed ball of stars roughly 8,000 light years in diameter, out of which a bar of stars some 27,000 light years long emerges. The bar points more or less directly towards our Solar System, and as a result its existence was uncertain until it was finally confirmed by NASA's infrared Spitzer Space Telescope in 2005.

> "The most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms"

Two major spiral arms emerge from the ends of this bar. Until recently, our galaxy was thought to have four major arms, but further observations have led to two of them being 'downgraded'. The two survivors are known as the Scutum-Centaurus Arm and the Perseus Arm. They alternate with the two recently demoted arms – the Sagittarius and Norma arms. The picture is complicated by numerous other disconnected regions that follow the general sweep of the spiral arms. For instance, our own Solar System lies on the inside edge of a 10,000 light year fork in the Sagittarius Arm, known as 'Orion Spur', while both the Sagittarius and Norma arms are thought to trail off into disconnected clumps that wrap their way around the galaxy's outer perimeter. The outer extension of the Norma Arm, which lies on our side of the galactic centre and is therefore more easily seen, is known as the Outer Arm.

The Milky Way's spiral arms are not permanent, linked structures – otherwise the differential rotation discovered by Jan Oort would cause them to 'wind up' after just a few rotations. Instead, they perpetually renew themselves. In fact, the arms seem to be celestial traffic jams, created where stars and gas in circular orbits around the galactic hub enter a spiral 'density wave' region where they are slowed down and jammed together. This triggers the creation of new star-forming nebulas that light up the spiral arms with the pinkish glow of hydrogen emission, and ultimately give birth to 'open clusters' of stars.

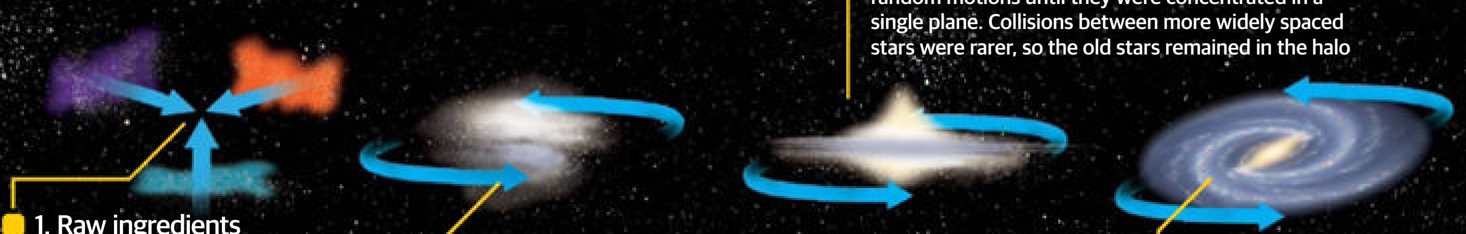
However, these stellar foundries are short-lived on a galactic timescale – they exhaust their supplies of star-forming gas within a few million years, and the heaviest stars squander their fuel in a few million more. As a result, the most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms – instead it's the more sedate, longer-lived stars like our own Sun that make it out of the traffic jam to continue their orbits around the galactic disc over billions of years.



Viewing our galaxy from Earth

As early as the 18th Century, astronomers realised that the winding path of the Milky Way across the sky is a result of our location in a broad, relatively flat plane of stars. But our Solar System's location sandwiched between the major spiral arms complicates the picture considerably, so that different arms in different parts of the sky run together and overlap in places to form a seamless river of light. The picture is further complicated by the presence of dark dust lanes that obscure the light of more distant star clouds: perhaps the most famous of these is the Great Rift, which runs through the constellations of Cygnus and Aquila. The brightest and broadest part of the Milky Way, meanwhile, lies in the direction of Sagittarius and Scorpius. It consists largely of the Carina-Sagittarius Arm and marks the direction of the hub and galactic centre. On the opposite side of the sky, meanwhile, the Perseus Arm runs around the outer edge of the galaxy as seen from our point of view.

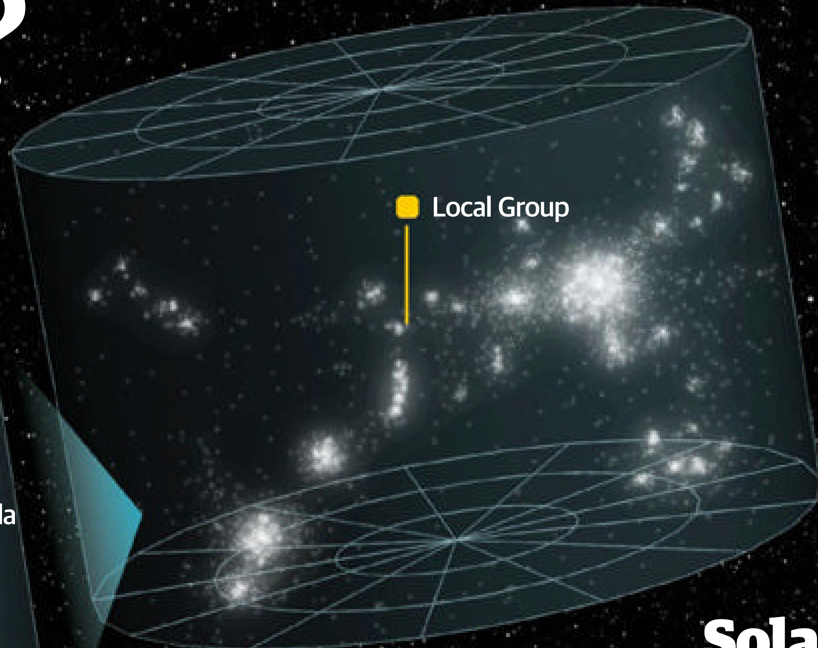
Birth of the Milky Way



Where is our galaxy?

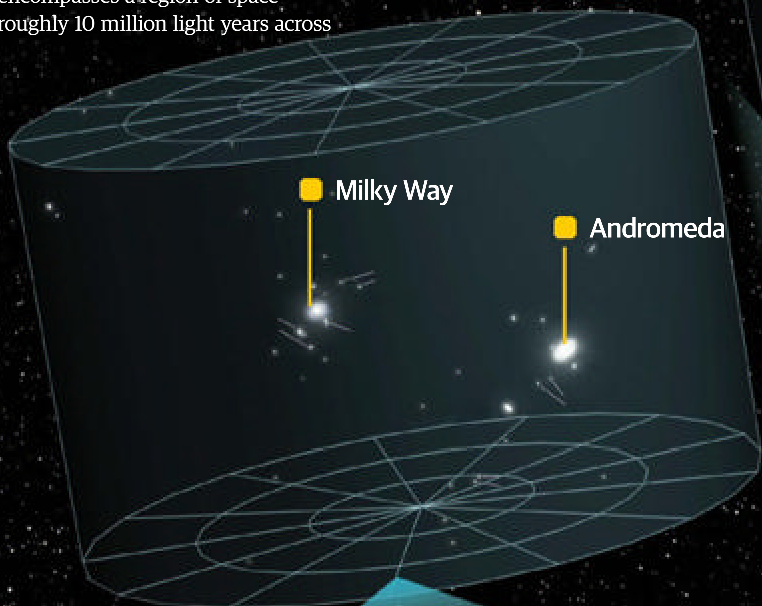
Virgo Supercluster

The Local Group lies on the outskirts of a galaxy supercluster centred around the Virgo Cluster, some 60 million light years away



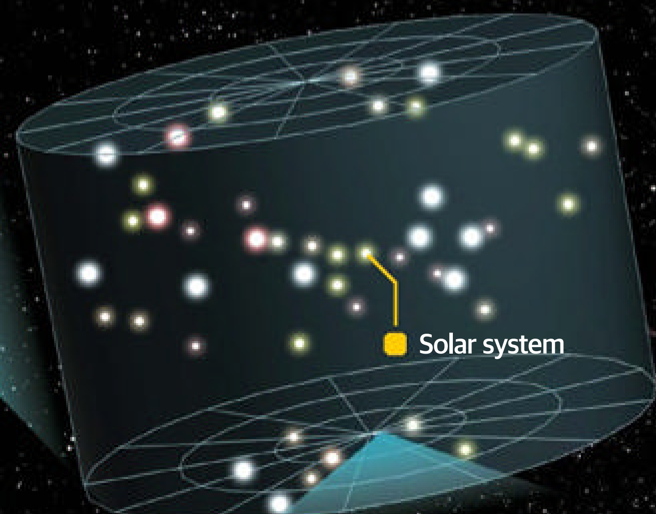
Local Group

This cluster of galaxies, dominated by the Milky Way and Andromeda, encompasses a region of space roughly 10 million light years across



Solar neighbourhood

Our region of the Milky Way contains a mixture of single and multiple stars of many different types, separated by a few light years on average

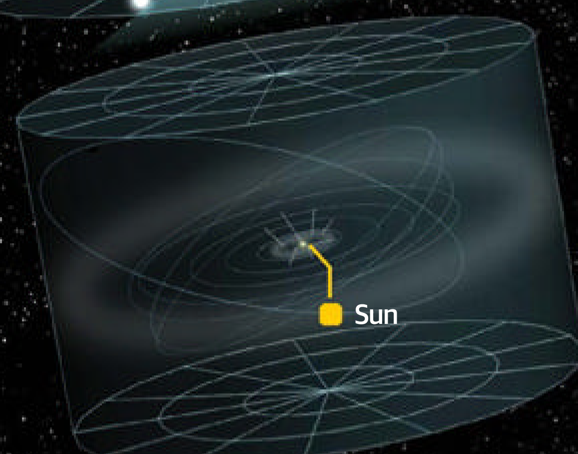


Galactic influence

The Milky Way is roughly 100,000 light years across, but its gravitational influence covers a region several hundred thousand light years wide

Our Solar System

Out to the edge of the Kuiper belt (the zone of small, distant icy dwarf worlds) our Solar System is roughly a light day across



At the inner limit of the spiral arms, the bar and hub are surrounded by a structure known as the 5-kiloparsec Ring (one kiloparsec is around 3,260 light years). Although we cannot see it in visible light, the ring seems to contain huge concentrations of star-forming nebulas and young stars: it's probably the main generator of new stars in the Milky Way.

Above and below the main disc lies a relatively empty region known as the halo. Many faint, long-lived stars pass through this region on tilted orbits, but the halo's most obvious occupants are globular clusters – dense balls containing many tens of thousands of old, red and yellow stars that are generally found above and below the galactic hub. Similar red and yellow stars dominate the hub and bar – they are relatively poor in heavy elements, which allows them to shine for billions of years without evolving significantly. As a result, they are known as 'Population II' stars, in contrast to the younger, faster-evolving and heavy-element-enriched 'Population I' stars in the galactic disc.

Among all these stars, the huge majority are low-mass red and orange dwarfs – stars with a fraction of the mass of the Sun, which shine so faintly that they can only be seen when they are relatively nearby. Brighter and more massive stars are much rarer, but tend to shine out over huge distances and so appear more prominently in our skies. Similarly, ageing but brilliant red and orange giants are common among the naked-eye stars seen from Earth, but in fact far rarer than they might appear at first glance.

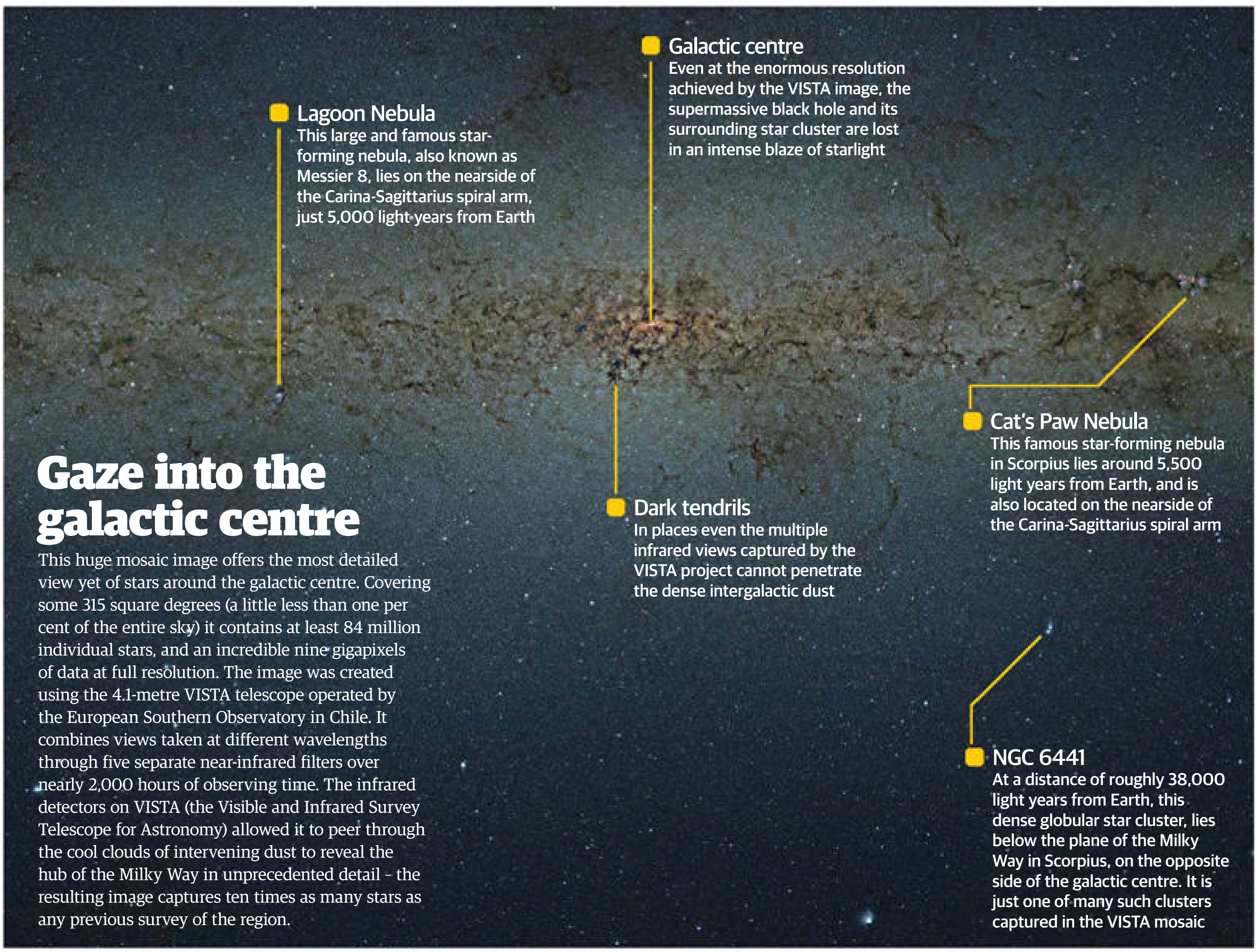
What's more, stars in our galaxy seem to be gregarious – although they gradually drift apart from the open clusters in which they form, many stars remain together in binary or multiple star systems. Recent research also suggests that planetary systems are also common – there may be at least as many planets as there are stars in the sky.

Within the hub, stars become more densely packed towards the centre of the Milky Way – the galactic core. Only X-rays, radio waves and some infrared waves can pass through these dense star clouds unaffected, but they reveal an intriguing picture of the strange and violent conditions in the core itself.

At radio wavelengths, the core is marked by a complex radio source known as Sagittarius A – it consists of a bubble-like structure (Sagittarius A West) a few tens of light years across – probably the remnant of an enormous supernova explosion. Embedded within this is a three-armed spiral called Sagittarius A East, roughly ten light years across. The middle of the spiral coincides with the densest concentration of stars in the Milky Way, and a third, point-like source of radio waves known as Sagittarius A* that is believed to mark the Milky Way's centre.

X-ray emissions reveal huge bubbles and twisted lobes of superhot gas across the region – a mix of supernova remnants and the effects of hot stellar

"The Milky Way is a major component of the Local Group – a small galaxy cluster some 10 million light years across"



Gaze into the galactic centre

This huge mosaic image offers the most detailed view yet of stars around the galactic centre. Covering some 315 square degrees (a little less than one per cent of the entire sky) it contains at least 84 million individual stars, and an incredible nine gigapixels of data at full resolution. The image was created using the 4.1-metre VISTA telescope operated by the European Southern Observatory in Chile. It combines views taken at different wavelengths through five separate near-infrared filters over nearly 2,000 hours of observing time. The infrared detectors on VISTA (the Visible and Infrared Survey Telescope for Astronomy) allowed it to peer through the cool clouds of intervening dust to reveal the hub of the Milky Way in unprecedented detail – the resulting image captures ten times as many stars as any previous survey of the region.

Studying the Milky Way

Detector instruments
Two different instruments – the High-Resolution Camera and the Advanced CCD Imaging Spectrometer – can record images from the X-rays or detect their different energy levels

Mirror assembly
Powerful X-rays pass straight through normal mirrors, so Chandra uses a series of nested metal cones at shallow angles, which ensure the X-rays ricochet to a focus

Mission profile
Chandra X-ray Observatory

Launch date: 23 July 1999
Launch vehicle: Space Shuttle Columbia
Mass: 4,790kg
Telescope diameter: 1.2m
Mission: Chandra was designed to image the high-energy X-ray sky at higher resolutions than ever before, detecting phenomena such as hot interstellar and intergalactic gas clouds, black holes and other stellar remnants.
Key discoveries: Chandra has allowed the region around Sagittarius A* to be imaged in detail, while the X-ray echoes it has detected have shown that the supermassive black hole has been active in the recent past.

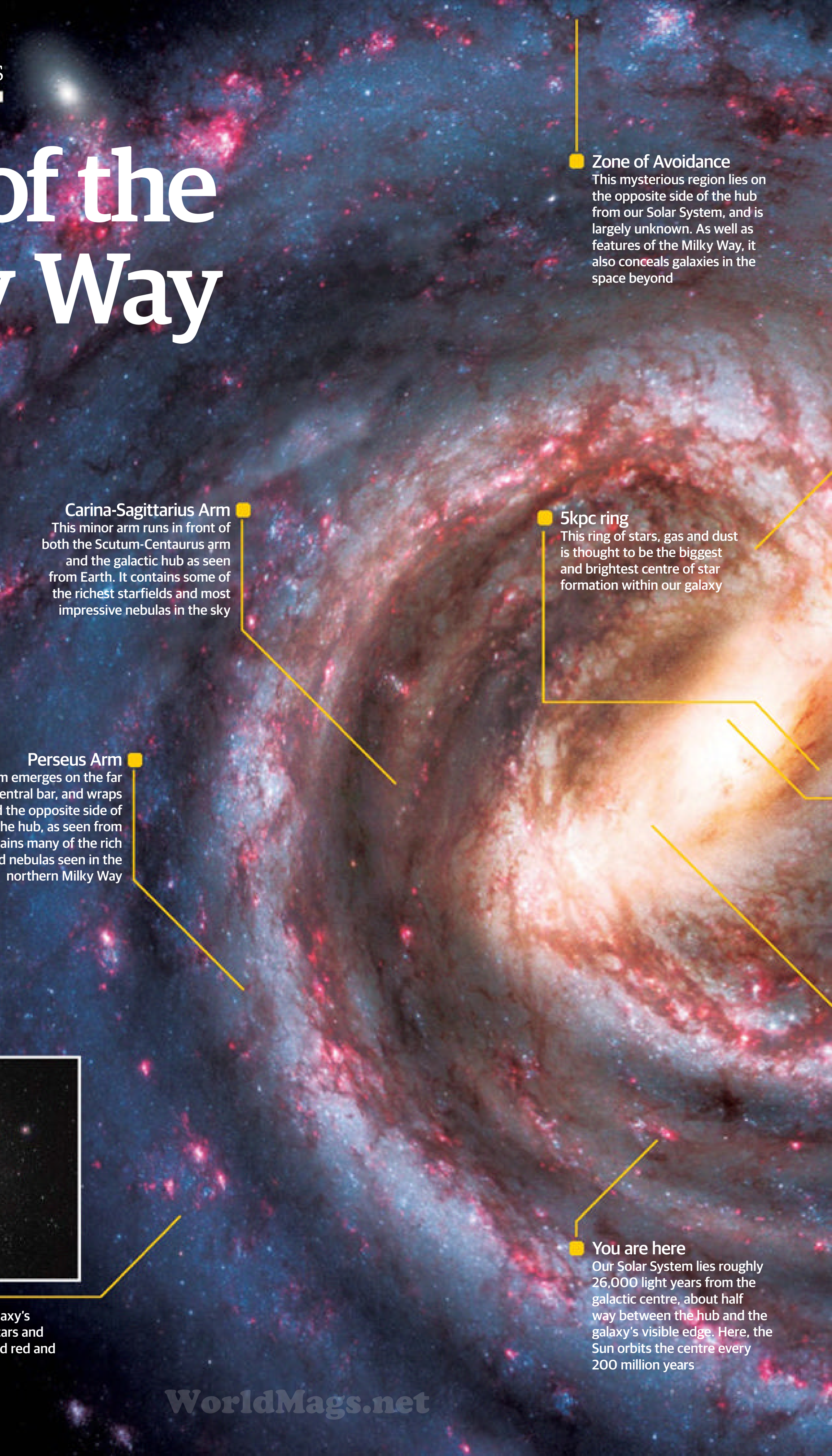
Cool telescope
Spitzer collects infrared with a beryllium-mirrored telescope that was cooled to -268°C (-450°F) using liquid helium so as not to swamp the weak heat radiation

Sun shield
Spitzer's ingenious solar shield allows it to continue operating at low temperatures even after its liquid helium coolant has been exhausted

Mission profile
Spitzer Infrared Space Observatory

Launch date: 25 August 2003
Launch vehicle: Delta II
Mass: 950kg
Telescope diameter: 0.85m
Mission: Spitzer was designed to study a wide range of objects, from star-forming nebulas and newborn solar systems to distant galaxies. Although the coolant required for its primary mission was exhausted in May 2009, it is still operational in its 'Warm Mission' phase.
Key discoveries: Spitzer's infrared vision allowed it to pierce the dust that blocks our view of the galactic centre, providing the first detailed images of the giant star clusters and tortured gas clouds found in the region.

Map of the Milky Way

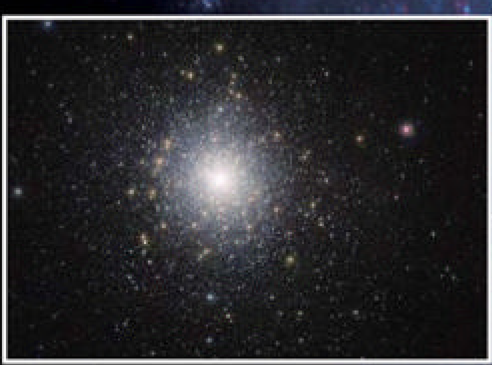


Zone of Avoidance
This mysterious region lies on the opposite side of the hub from our Solar System, and is largely unknown. As well as features of the Milky Way, it also conceals galaxies in the space beyond

Carina-Sagittarius Arm
This minor arm runs in front of both the Scutum-Centaurus arm and the galactic hub as seen from Earth. It contains some of the richest starfields and most impressive nebulas in the sky

5kpc ring
This ring of stars, gas and dust is thought to be the biggest and brightest centre of star formation within our galaxy

Perseus Arm
This major arm emerges on the far side of the central bar, and wraps its way around the opposite side of the sky from the hub, as seen from Earth. It contains many of the rich starfields and nebulas seen in the northern Milky Way



Galactic halo
The halo region above and below the galaxy's flattened disc is home to stray ancient stars and globular clusters – huge balls of long-lived red and yellow stars

You are here
Our Solar System lies roughly 26,000 light years from the galactic centre, about half way between the hub and the galaxy's visible edge. Here, the Sun orbits the centre every 200 million years

Scutum-Centaurus Arm
This major spiral arm emerges from the near end of the galaxy's central bar, but lies largely on the opposite side of the hub from Earth

SagDEG
Discovered in 1994 as an unusual concentration of stars on the far side of the galactic hub, the Sagittarius Dwarf Elliptical is a small galaxy in the process of being torn to shreds by the Milky Way's gravity

Sagittarius A*
The supermassive black hole at the centre of our galaxy weighs more than 4 million Suns, but only gives its presence away through X-ray and radio emission

Galactic hub
The central bulge of the Milky Way is roughly 8,000 light years in diameter and dominated by tightly packed, long-lived red and yellow stars

winds blowing out from massive stars. Infrared telescopes, meanwhile, show the distribution of stars themselves – the region is home to two of the largest open clusters in the galaxy, the Quintuplet Cluster and the Arches Cluster. A third cluster surrounds the Sagittarius A* region itself, but while its individual stars have been mapped, none coincides exactly with the mysterious radio source.

Since the Seventies, astronomers have suspected that Sagittarius A* might mark the location of an invisible black hole with the mass of millions of Suns, but the evidence to back this up has only recently been found. By mapping the central star cluster over several years, astronomers have plotted the orbits of two stars that orbit the object every few years. Based on the speed of these stars, Sagittarius A* must contain the mass of at least 4 million Suns concentrated in a region roughly the size of Uranus's orbit around the Sun. With such enormous density, it can only be a supermassive black hole.

However, Sagittarius A* seems surprisingly quiet compared to similar objects elsewhere in the universe – other supermassive black holes in distant galaxies wreak havoc with their surroundings. Astronomers think the big difference is that these black holes are feeding on material that strays too close. Sagittarius A*, on the other hand, seems to have long ago cleared out its immediate surroundings, and anything that still orbits in the central region stays safely out of reach.

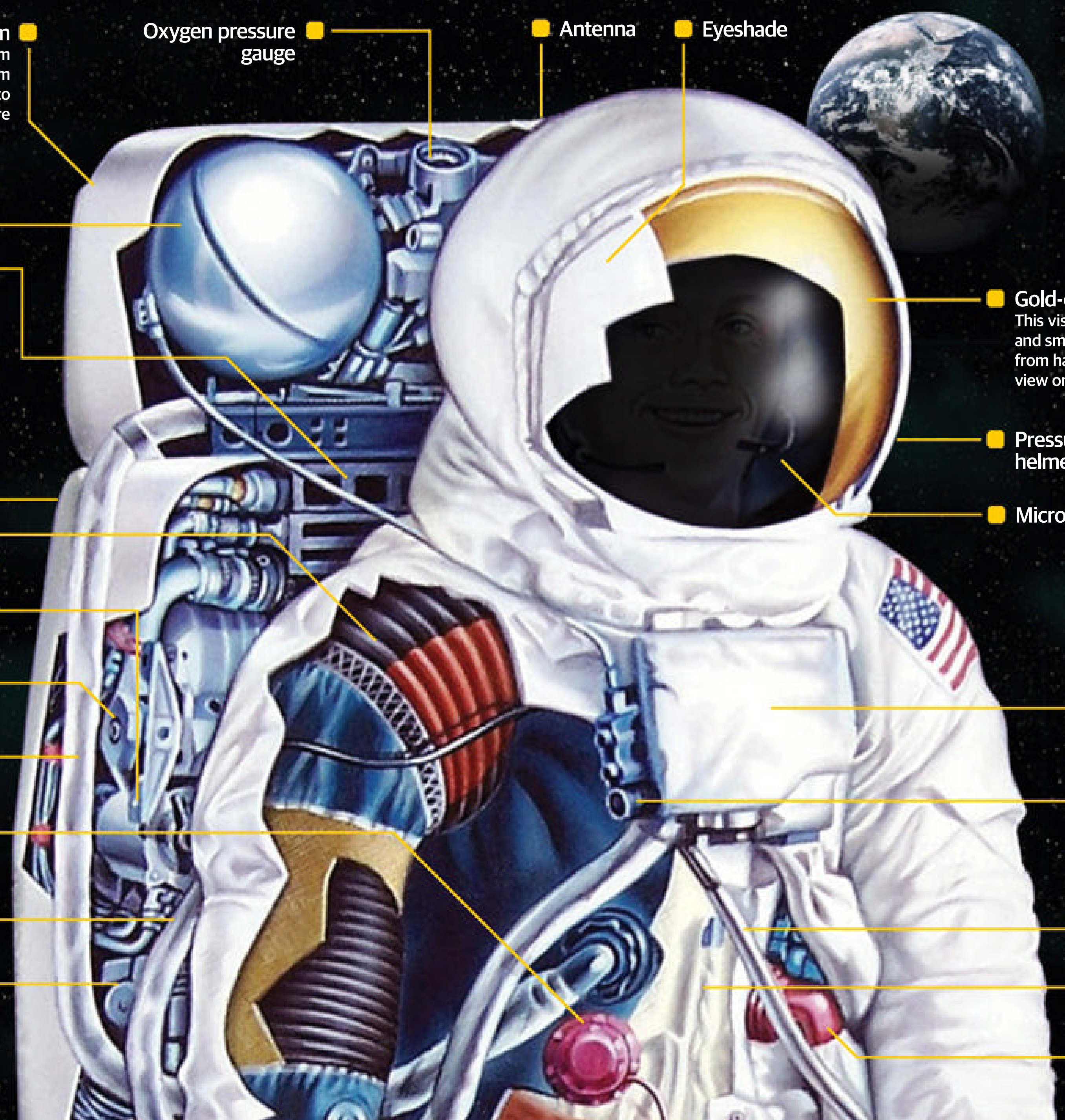
Recent discoveries, however, suggest that Sagittarius A* may have been active surprisingly recently. In 2007, NASA's Chandra satellite discovered X-ray 'echoes', created as radiation when an event roughly 50 years previously affected gas clouds near the central black hole. It seems likely that Sagittarius A* took a substantial snack at this time, when a large gas cloud strayed too close. And in 2010, the Fermi Gamma-ray Space Telescope found evidence for an even larger outburst thousands of years ago.

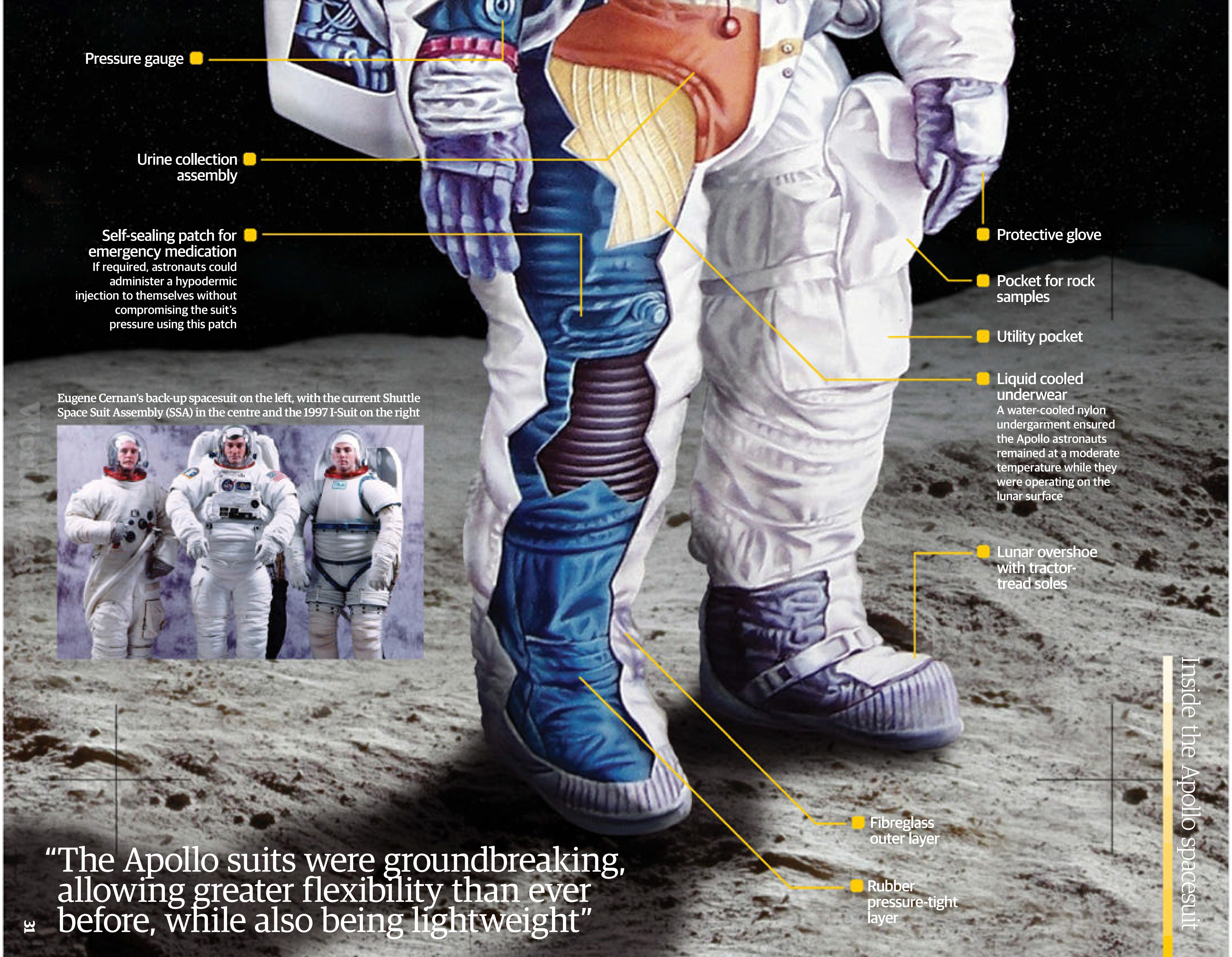
There's one final question that's worth asking about our galaxy – where does it end? Although the spiral arms seem to lose their intensity and the number of disc stars falls off dramatically over 50,000 light years from the hub, a disc of neutral hydrogen gas extends out to almost 100,000 light years and seems to retain the overall spiral structure. The Milky Way's gravitational influence extends even further – the halo of stars and globular clusters reaches out to around 150,000 light years or more. However, beyond this distance the orbits of halo objects are disrupted by two interlopers – the Magellanic Clouds. Until recently, these two irregular clouds of gas were believed to be in orbit around our galaxy, but it now seems that they are merely passing by on their own paths through space.

On a larger scale, the Milky Way is one of the major components of the Local Group – a galaxy cluster 10 million light years across. The other is the Andromeda Galaxy, some 2.5 million light years away. These two galaxies exert a strong influence on everything in their vicinity, and are approaching each other at 110 kilometres per second. They will eventually collide and merge together about 4 billion years from now in a process that will signal the end of the Milky Way as an independent galaxy.

Inside the Apollo spacesuit

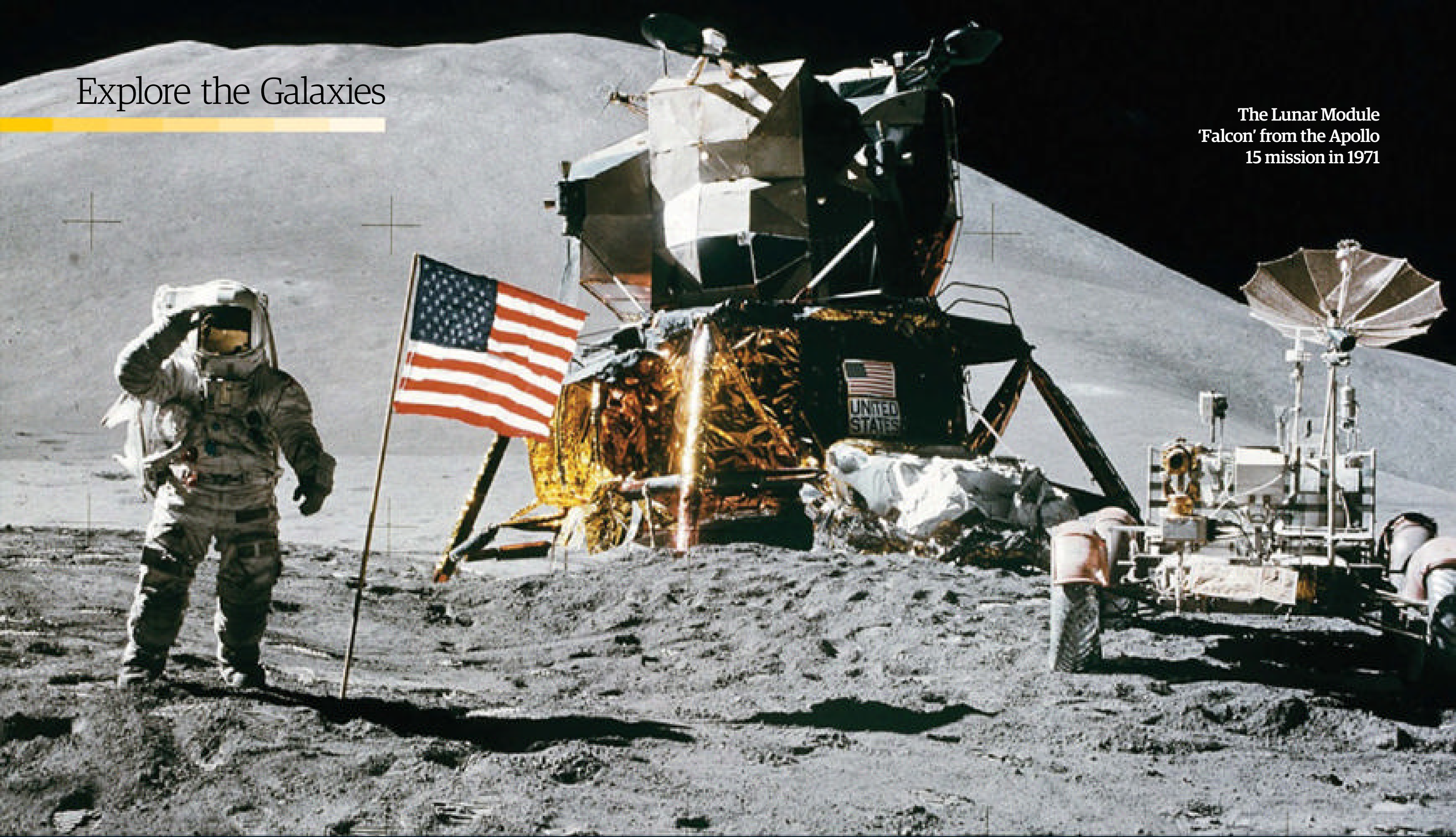
Take a look inside the suit that Neil Armstrong wore on the Moon





Eugene Cernan's back-up spacesuit on the left, with the current Shuttle Space Suit Assembly (SSA) in the centre and the 1997 I-Suit on the right

"The Apollo suits were groundbreaking, allowing greater flexibility than ever before, while also being lightweight"



The Lunar Module 'Falcon' from the Apollo 15 mission in 1971

The 1969 Lunar lander

The Lunar Module was the first manned spacecraft specifically built to deliver men to the Moon

This two-stage spacecraft was built by the Grumman Aircraft Engineering Corporation to ferry two astronauts and scientific equipment to the surface of the Moon. The 6.7-metre (22-foot) tall craft had an aluminium frame with titanium fittings and was covered with layers of aluminised Kapton and aluminised Mylar to provide thermal protection against micrometeoroids.

The Apollo Command Module carried it into lunar orbit, and two of the three crew transferred to it and used the descent engine to land on the Moon. After deploying scientific experiments and collecting samples, the ascent stage blasted off using the descent stage as a launching pad. Back in lunar orbit, it docked with the Command Module, and once the astronauts were back on board the ascent stage was jettisoned. Before the Lunar Module (LM) could be used for the Moon landing mission it went through a rigorous programme of development and testing.

In 1962, the first designs envisaged a squat vehicle with large windows but by 1965 it evolved into a lighter and taller, triangular-windowed craft.

The Apollo 5 mission was the first test flight of the LM-1 on 22 January 1968. A Saturn 1B rocket put the unmanned craft into Earth orbit where the descent and ascent rocket engines were tested to simulate a mission abort and a deceleration burn required for a lunar landing.

The mission was deemed so successful that a further test mission with LM-2 was abandoned. Apollo 9 became the first manned mission for LM-3 ('Spider'), which was launched into Earth orbit on 3 March 1969. Commanded by James McDivitt, the systems of the LM were tested and it performed docking manoeuvres with the Command Module.

LM-4 'Snoopy' was the first LM to be tested in lunar orbit, and its closest approach took it within 15.6 kilometres (9.7 miles) of the Moon before it returned to the Command Module. This dress rehearsal in May 1969 went perfectly but the LM was a test version that was too heavy to launch itself off the lunar surface.

Finally, Apollo 11's LM-5 'Eagle' took Neil Armstrong and Buzz Aldrin to the Moon on 20 July 1969. However, it was not a straightforward landing as the astronauts had to override their craft's computer otherwise they would have landed in an unplanned rocky area. Apollo 12's LM-6 'Intrepid' in November 1969 also made a successful landing on the Moon. Despite the odd glitch, the Moon missions ran successfully until the Apollo 13 mission.

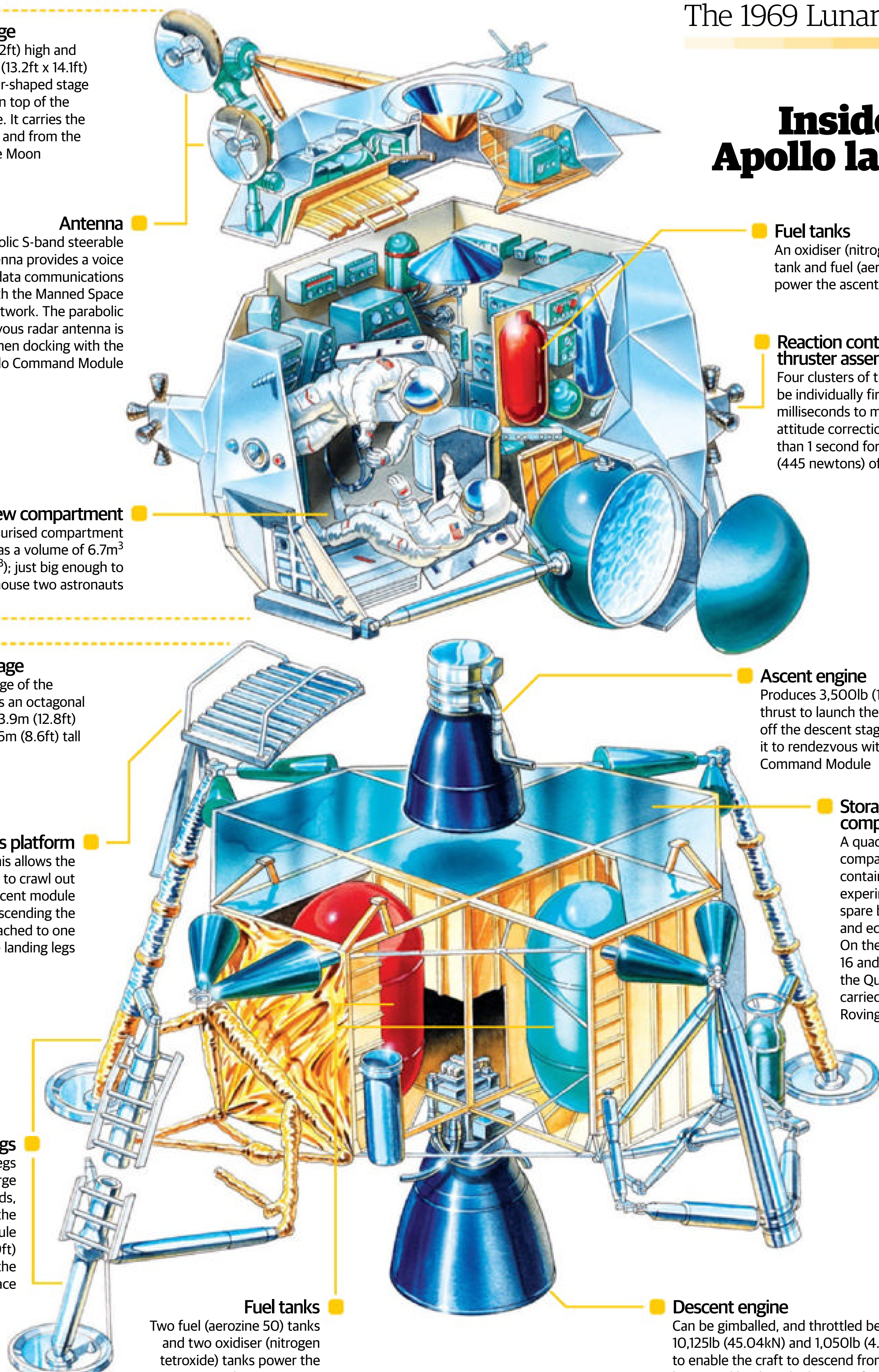
At a distance of around 320,000 kilometres (200,000 nautical miles) from Earth an oxygen tank in the Command Service Module exploded, and it immediately became a mission to safely return to Earth rather than a trip to the Moon. For four days the crew took refuge in the LM-7 'Aquarius' until they could use the Command Module to re-enter the Earth's atmosphere.

From Apollo 12 to Apollo 14, which used LM-8 'Antares' to land on the Moon in February 1971, H-series precision Landing Modules were used that could sustain two-day long stays on the Moon. LM-9 a H-series module was scheduled for the Apollo 15, but it was replaced with the improved J module series that carried the Lunar Roving Vehicle. J-series modules continued to be used up to the last Apollo 17 mission in December 1972.

In the late-Sixties, there were plans for an LM Truck that would replace the manned ascent stage of the LM with a cargo-carrying stage. This would be capable of delivering 5,000 kilograms (11,000 pounds) of equipment and supplies to support manned Lunar activities.

It is remarkable that after more than 40 years this is the only manned vehicle to land on the Moon.

Inside the Apollo lander



Ascent stage
This 2.8m (9.2ft) high and 4.0m x 4.3m (13.2ft x 14.1ft) wide, irregular-shaped stage is mounted on top of the descent stage. It carries the astronauts to and from the surface of the Moon

Antenna
The parabolic S-band steerable antenna provides a voice and data communications link with the Manned Space Flight Network. The parabolic rendezvous radar antenna is used when docking with the Apollo Command Module

Crew compartment
The pressurised compartment has a volume of 6.7m^3 (235ft^3); just big enough to house two astronauts

Fuel tanks
An oxidiser (nitrogen tetroxide) tank and fuel (aerozine 50) tank power the ascent engine

Reaction control thruster assembly
Four clusters of thrusters can be individually fired for a few milliseconds to make fine attitude corrections, or longer than 1 second for 100 pounds (445 newtons) of steady thrust

Descent stage
The lower stage of the spacecraft has an octagonal prism shape, 3.9m (12.8ft) across and 2.6m (8.6ft) tall

Egress platform
This allows the astronauts to crawl out of the ascent module before descending the ladder attached to one of the landing legs

Landing legs
The four legs have large landing pads, and hold the Lunar Module 1.5m (4.9ft) above the lunar surface

Ascent engine
Produces 3,500lb (16kN) of fixed thrust to launch the ascent stage off the descent stage, and enables it to rendezvous with the Apollo Command Module

Storage compartments
A quadrant of compartments contain lunar surface experiments, spare batteries and equipment. On the Apollo 15, 16 and 17 missions, the Quadrant 1 bay carried the Lunar Roving Vehicle

Fuel tanks
Two fuel (aerozine 50) tanks and two oxidiser (nitrogen tetroxide) tanks power the descent engine

Descent engine
Can be gimballed, and throttled between 10,125lb (45.04kN) and 1,050lb (4.7kN) of thrust to enable the craft to descend from lunar orbit, hover and land on the lunar surface

Mars lander

Life imitates art as NASA's flying-saucer spaceship design proves successful under test conditions

What's this? Perhaps a captured extraterrestrial spacecraft, or a scene from a new science-fiction movie? Actually, this is real technology and it's definitely not of alien origin. NASA's Low-Density Supersonic Decelerator (LDSD) is the space agency's latest flying-saucer-style landing craft project. It incorporates a Supersonic Inflatable Aerodynamic Decelerator (SIAD) – the doughnut-shaped structure that makes up most of the craft in this image.

The LDSD was tested at the end of June 2014, dropped from a high-altitude balloon from an altitude of around 36,500 metres (120,000 feet) over the Pacific Ocean. It took 30 minutes to make splashdown in the ocean below. Although one of the parachutes failed to deploy properly, the SIAD technology performed perfectly, which means there's every chance we could one day see it used to land a real manned Mars mission.

NASA's Low-Density Supersonic Decelerator was recovered from the ocean after completing its test with flying colours

SEARCH FOR LIFE

The five most important people in the search for extraterrestrial life

Dr John Mather
Dr Mather is a senior project scientist on NASA's James Webb Space Telescope. This giant space observatory will launch in 2018 and will aid in the hunt for potentially habitable planets outside our Solar System

Dr Jerry Ehman
Dr Ehman, now retired, is an American astronomer. He previously worked for SETI and in 1977 he discovered the famous Wow! signal, which just might have been our first contact from an intelligent alien race

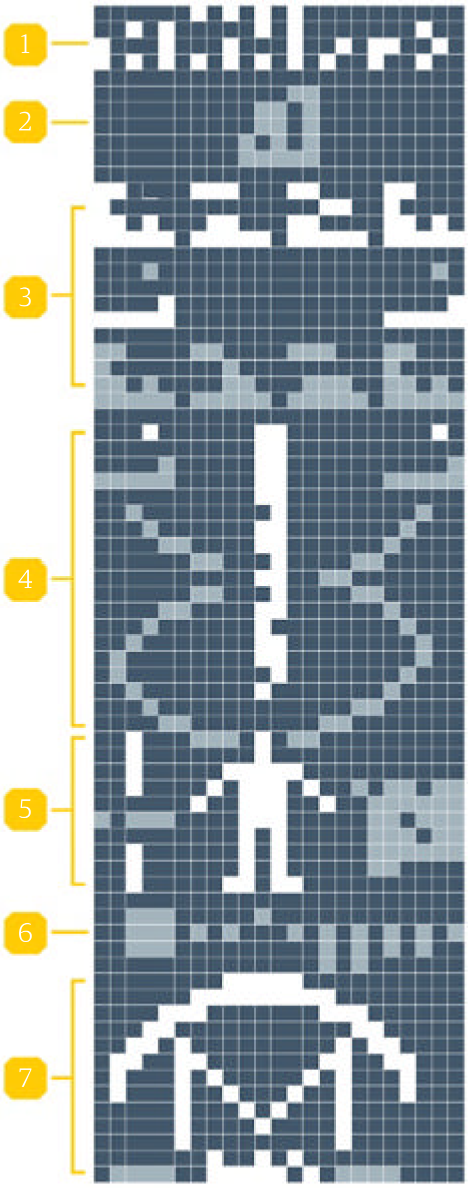
Dr John Elliott
Involved with SETI since 1999, Dr Elliott's research includes working out how we'd decipher and respond to an alien signal. He is a Reader in Intelligence Engineering at Leeds Metropolitan University in the UK

Dr Seth Shostak
As senior astronomer at the SETI Institute in Mountain View, California, Dr Shostak is actively involved in the hunt for intelligent life. He is also a writer and hosts the *Big Picture Science* radio show

Dr Jennifer Eigenbrode
Dr Eigenbrode is a biogeochemist at NASA who specialises in astrobiology. She's looking for signs of life in the smallest places, including looking for biosignatures in rocks and ice on Mars through the Curiosity rover

The Arecibo message

On 16 November 1974, astronomers including Dr Frank Drake and Carl Sagan devised a message to send into the distant reaches of space. The message was intended to show the possibilities of communication with a potential intelligent race, rather than actually attempting to make contact.



1. Numbers
The numbers one to ten written in binary.

2. DNA
These represent the atomic numbers of the elements that make up DNA.

3. Formula
These are the formulas for the sugars and bases in DNA.

4. Double helix
A graphic of the double helix structure of DNA.

5. Population
A figure of a human and Earth's population.

6. Solar System
A graphic depicting the Solar System.

7. Dish
A graphic of the Arecibo dish and its dimensions.

Every month we hear of incredible new exoplanets in planetary systems seemingly like our own, and we learn more in the search for past or present microbial life as missions like Curiosity gain worldwide attention, but for some reason the notion that we might be just one intelligent race among many is yet to receive much support from the public at large.

Many people today still seem to have the same opinion that was prevalent in the mid to late 20th Century, that aliens are something that belong only to the realm of science fiction, but this is in the face of overwhelming evidence to the contrary. With every passing year, every new discovery of an exoplanet, every observation of frozen or liquid water on other bodies in the Solar System, it becomes harder and harder to argue that we are alone in our galaxy, let alone the entire universe.

In fact, it's a position that even notable astronomers are taking up. "We can't be the only instance of a race, we just can't be," said the late Sir Patrick Moore when talking to us in 2012, and he is joined by many others around the world who are coming around to the realisation that to think humanity is the only instance of intelligent life is implausible, ignorant and just plain naive.

For about half a century we have begun to seriously consider the possibility that we are not alone, and to prove this hypothesis scientists have focused on three areas of research, each equally capable of becoming the first to discover life outside of the confines of Earth. Throughout this feature we've spoken to the five most important people within these fields to find out what progress they're making in the search for life.

The first is the Search for Extraterrestrial Intelligence, or SETI, which is a privately funded international endeavour to discover signals from an alien race drifting through the cosmos. Next is the search for exoplanets (worlds outside our Solar System), an area of research that has only gained credence in the last couple of decades. The field of planet hunting may be young, but it is already providing us with fascinating results that may soon help us find an exoplanet just like Earth. The final area of research is the search for microbial life, fossilised or alive, on other worlds inside our Solar System. Until now this has largely focused on Mars, but places like Europa and Titan could also prove fruitful to explore.

The oldest of the three areas of research is SETI, using antennas around the world to look for alien signals. In 1959, Giuseppe Cocconi and Philip Morrison, two physicists from Cornell University in the USA, suggested for the first time that it might be possible to communicate with another intelligent race among the stars using microwave radio. "The probability of success is difficult to estimate," they wrote in the journal Nature, "but if we never search, the chance of success is zero."

At around the same time a young radio astronomer named Frank Drake came to the same conclusion, and in the following year he used a 26-metre (85-foot) telescope in West Virginia, USA, to conduct the first search for alien signals outside our Solar System. He found nothing, but his research (including the Drake equation, which estimates that the chances of life elsewhere in the universe is almost a certainty) sparked an interest around the globe that remains prevalent to this day. It was in fact the Soviet Union in the Sixties that first dominated SETI, observing huge portions of the sky at once. They were sure that there would be many advanced civilisations emitting

> "We can't be the only instance of a race, we just can't be" **Sir Patrick Moore**

The Arecibo Observatory in Puerto Rico

He'll be the person to know first

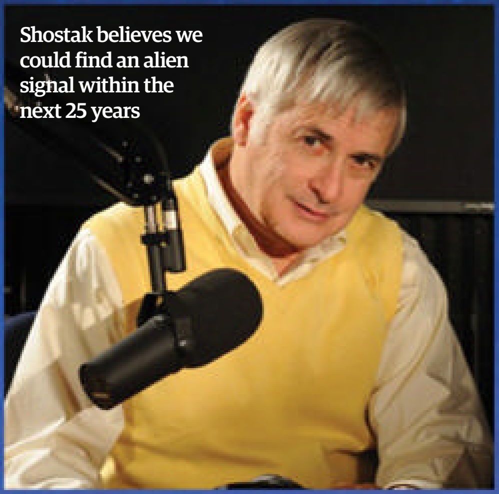
Dr Seth Shostak

How do you guys analyse incoming data at SETI?
The data analysis is all pretty automatic. Unless there's a signal that's looking very promising, and that only happens every couple of years, then you don't actually deal with the data processing. The algorithms in the software analyse them and do rather simple tests to try to prove if it's really ET, or if it's AT&T – interference from a telecommunications satellite or whatever.

Are there protocols in place for announcing the discovery of an alien signal?
We've been worrying about the protocols about what to do if we find a signal. We've rewritten them and they're all very nice in a nice little document, but the reality is that nobody's going to pay a whole lot of attention to protocols if we pick up a signal. And we know that because we've had false alarms, like in 1997 when for almost a day it looked like we had a signal that was the real deal. And did people stick to protocols and say, 'well, we've got to notify these people and those people?' No! None of that happened. It was completely chaotic, which it would be.

What's the next step after the discovery of a signal?
If you get a signal that looks like it might be ET on the line, the first thing you do is to spend an awful lot of effort trying to verify that, maybe several days. But in all that time while you're doing this there's no policy of secrecy, so lots of people know you've got an interesting signal. In 1997, when we had this promising signal there were no men in black, the government hadn't the slightest interest in any of it, but the media did and they started calling me up.

What happens next?
After that, every telescope in the world would be aimed in the direction of the signal to try to find out how far away it is and whether there are planets there. Keep in mind that the instruments [being] used by SETI are not capable of [deciphering] messages. You're getting the bottle [signal] without the message in it, but at least you've got the bottle so you know that somebody's trying to say something.

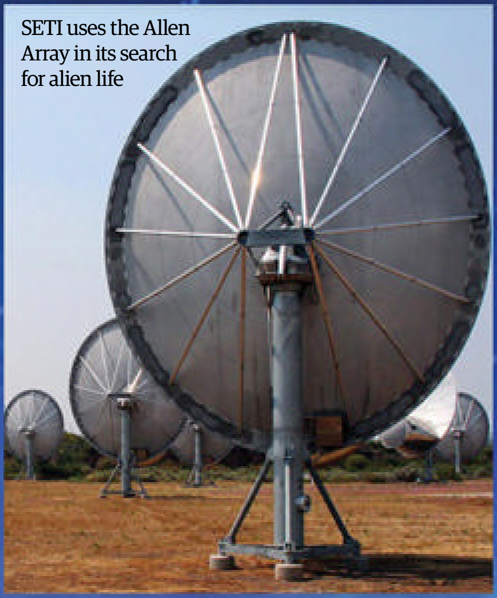


Shostak believes we could find an alien signal within the next 25 years

What would become of SETI?
There would suddenly no longer be a fight to try to get enough money to keep doing the SETI experiment. There would be enough money to build much bigger instruments and go back and possibly find any message. I'm sure there would be a message there. I think that immediately SETI would be vaulted from sort of a backburner niche science experiment to something that many, many people were doing. That's exactly what happened with the discovery of planets around other stars. There were a couple of guys doing it in the world, and suddenly it became an industry. That's what would happen with SETI.

Would we understand the message?
My guess is they're likely to be hundreds of thousands of years, maybe more, beyond us. And for us to understand the information content of their transmissions is probably asking too much. But at least you'd know they were there, and that's really the idea, isn't it? You would know that what we have here on Earth is pretty nifty, but it's not a miracle.

Are you confident we'll find a signal?
I bet everyone here a cup of coffee that we'll find aliens within two dozen years.



SETI uses the Allen Array in its search for alien life

BIO

Dr Seth Shostak
Dr Shostak is the senior astronomer for the SETI Institute in Mountain View, California. He is actively involved in the hunt for alien signals. He is also a writer and hosts a weekly science radio show.

"In 1997, for almost a day it looked like we had a signal, that was the real deal"

The next great planet hunter

Dr John Mather

BIO

Dr John Mather

Dr Mather is a senior project scientist on the James Webb Space Telescope. He is also a senior astrophysicist in the Observational Cosmology Laboratory at NASA's Goddard Space Flight Center.

What's your role on the James Webb Space Telescope (JWST) project?
I'm the senior project scientist, which means that I work with the project management and engineering teams to define the mission requirements to make sure that they are correctly implemented, and with the scientific teams to make sure we have understood the scientific opportunities and their implications for what should be built to enable spectacular discoveries.

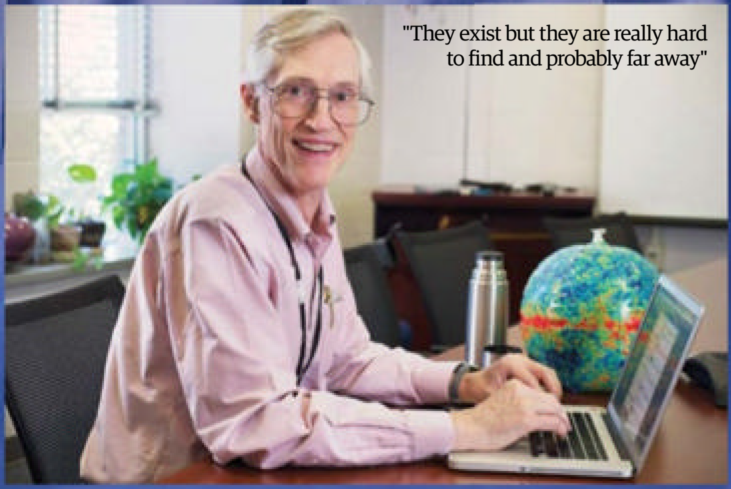
What work will you be doing in the coming years, and post launch in 2018?
I'll be continuing my role as senior project scientist to make sure our mission realises its potential. Post launch I anticipate writing observing proposals and working with colleagues to write up the results. I hope to be lucky and find something that's a great surprise.

How will JWST aid in the hunt for exoplanets?
We have two main ways. First, we look at planets directly with coronagraphs in three of the four instruments. Coronagraphs block out the direct starlight so we can look for planets orbiting nearby, which is primarily valuable for large and young planets. Second, we watch a star get fainter when a planet goes in front of or behind its star [which is known as 'transiting']. We can get amazing details about the planets and their atmospheres from this data. The Kepler mission has given us thousands of candidate planets [using the transiting method] and they are all interesting. If we can get a really good target there is the possibility that we could find signs of water around a large version of Earth, and then we would think such a planet could harbour life.

Could a separate star shade be flown near the James Webb Space Telescope to block out the light of distant stars and help find planets?
Yes, of course! Our team considered star shades in the very early days of conceiving the mission, but the technology was clearly not ready in 1996. Now, much work has been done by university groups and aerospace firms like Northrop Grumman and Lockheed Martin, and we know quite well how to design such a shade. In my opinion it could be done for a budget that would be worth the fabulous planet measurements that could be made. Either a star shade could be built to fly near to JWST, or a star shade could be made to work with a new telescope. Both are difficult but possible.

Do you think we'll find an Earth-replica before JWST launches in 2018?
Yes, I think the Kepler mission will find planets a lot like Earth, in the sense of being the right size and temperature, orbiting stars a lot like the Sun. But we probably won't know much about their properties, so we won't be able to say they are 'exactly' like Earth.

Do you think we will ever make contact with an intelligent alien race?
I don't think we will make contact with an intelligent extraterrestrial race any time soon. I think they exist but they are really hard to find and probably far away. On the other hand, I really do think it's worth trying! We already have technology that could send detectable signals across our whole galaxy, but it would only work if somebody on the other end knew how to receive them. Now our job is to guess how to eavesdrop on those other civilisations, if they exist.



"They exist but they are really hard to find and probably far away"

The James Webb Space Telescope is set to launch in 2018

Did he already make contact?

Dr Jerry Ehman

What are you working on at the moment?
I am retired. I enjoy bowling and golf and am involved in church activities. I unvolunteered from the Ohio State University Radio Observatory back in 2008, so I am no longer actively working much in SETI.

What were you doing at the time you discovered the Wow! signal?
I was a professor in Management Science at another university in Columbus, Ohio. I was also a volunteer at the Ohio State University Radio Observatory (OSURO).

What was the Wow! signal?
It was a strong narrowband signal from an unknown object. The distance to that object could not be determined.

Did you believe the Wow! signal was a sign of extraterrestrial intelligence?
Since all of the possibilities of a terrestrial origin have either been ruled out or seem improbable, and since the possibility of an extraterrestrial origin has not been able to be ruled out, I must conclude than an extraterrestrial intelligence *might* have sent the signal that we received as the Wow! source.

Where do you think it came from?
After some analysis and thought, it became quite obvious that this signal came from some object a large distance away from the Earth (well beyond the distance of the Moon).

Could we have learned more about the signal if more resources had been available?
At the time, personal computers didn't exist. If we had today's equipment, much more could have been learned. For example, it might have been possible to detect the modulation [information] components of the signal.

Do you think we'll detect a signal from an intelligent race in the coming years?
I'm certainly hopeful.

Will we ever contact alien life?
Contact is less likely than the detection of a signal, although I'm also hopeful that contact will occur some time in the next billion years or so.

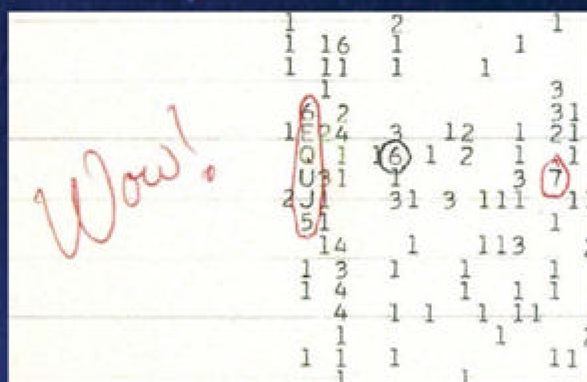
Do you think life is out there?
Absolutely!

BIO

Dr Jerry Ehman
Dr Ehman, now retired, is an American astronomer. He holds a PhD in astronomy from the University of Michigan. In 1977, while working on the Big Ear radio telescope at the Ohio State University, he discovered the famous Wow! signal.

The Wow! signal

One of the most famous instances of the detection of possible alien life was a radio signal that has been dubbed the Wow! signal, owing to Jerry Ehman (above) circling the signal in excitement. Ehman discovered the signal on 15 August 1977 while working on a SETI project. The circled code, '6EQUJ5', indicated an increased intense signal that seemingly came out of nowhere.



huge amounts of power that would be easy to spot, but this was not so.

It was widely believed that SETI had a good chance of success, though, so in the Seventies NASA threw its hat into the ring. It established SETI programmes in California at its Ames Research Center in Mountain View and the Jet Propulsion Laboratory in Pasadena to look for signals around stars like our Sun or otherwise. In the mid-Nineties, however, funding was cut, and the SETI Institute was forced to go it alone.

SETI uses a number of antennas and arrays around the world, such as the Allen Telescope Array in California, to observe distant stars and discern whether they are emitting any artificial signals produced by an intelligent race. Within minutes of observing a star they have an answer, but to this day they have yet to find any conclusive evidence of extraterrestrial intelligence. Undeterred, workers at SETI continue to search for signs of life, and they're extremely confident that they will find something.

To aid in SETI's study, the hunt for habitable exoplanets might allow us to find worlds where life could reasonably be thought to reside. Finding habitable exoplanets that SETI can study for signals is something that will prove of great importance. Of course, planet hunting itself is an area of astronomy that is not even two decades old - the first exoplanet was not discovered until 1995. But while planet hunting might still be in its infancy, the results we have obtained from just a handful of telescopes are astounding. NASA's Kepler space telescope, which launched from Cape Canaveral in March 2009, has found thousands of planet candidates in barely four years of operations, and some of these offer tantalising hints of being habitable.

But Kepler is looking at just a tiny portion of our giant Milky Way, which in turn is relatively small in the grand scheme of the universe. Based on data from Kepler, astronomers at the Harvard-Smithsonian Center for Astrophysics estimated in January 2013 that there were at least 17 billion Earth-sized exoplanets in the Milky Way. That's not a typo; billion, not million. Consider that there are about 100 billion galaxies in the known universe, and things start to get really exciting. Is it really possible that, out of 1.7 trillion trillion potential planets in the 13.7 billion-year-old universe only one, Earth, had the necessary conditions to produce intelligent life? Many leading scientists believe this to be unlikely.

Kepler, however, can only reveal very basic data about an exoplanet, including its size, mass and orbit. Future telescopes, like NASA's James Webb Space Telescope, will allow us to study these planets in even more detail. This giant space observatory, which will launch in 2018, might be able to directly image exoplanets and even reveal the composition of

Dr Eigenbrode believes that if alien life exists beyond Earth it is most likely microbial

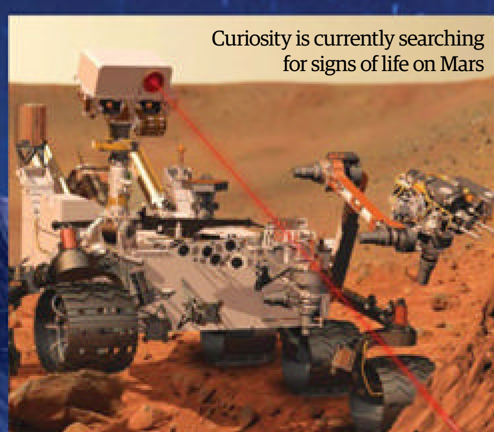
Looking for life in small places

Dr Jennifer Eigenbrode

What's your role at NASA?
I am a research scientist at NASA Goddard Space Flight Center. My studies focus on understanding the sources, alteration, and preservation of organic molecules in geological materials on Earth and Mars. I am a participating scientist on the Mars Science Laboratory [Curiosity] and a collaborator for the Sample Analysis at Mars [SAM] instrument suite that can detect organics in Gale Crater sediments.

Do you think we'll find evidence of past or present life on Mars?
I think Mars may have harboured life in the past. The conditions of Mars 3.5 billion years ago were probably similar to the conditions of Earth. Both were likely habitable. If past life did exist on Mars, then there should be a record of it in the sediments. If life didn't exist on Mars, we may expect to find meteoritic or geological organic matter. Hopefully, we'll find preserved organics in the surface sediments at Gale Crater where the MSL rover is exploring. Exploration by the ESA/NASA ExoMars rover [due to land in 2018] and the NASA Mars 2020 rover will be valuable in furthering our understanding of organic preservation on Mars.

Where else could we find organics in the Solar System?
Today, we find evidence of organics in interstellar gas particles, meteorites, comets and in some planetary atmospheres [such as methane on Mars and Titan]. There is every reason to suspect that organics have been distributed all over the Solar System. What we do not understand is what has happened to these organics since their initial distribution. What processes have altered them? Has life tapped their carbon and energy to support extraterrestrial ecosystems?



Curiosity is currently searching for signs of life on Mars

Do you think the Allan Hills 84001 meteorite contained fossilised life?
It was the publication of the suspected microfossils in this Martian meteorite that energised the field of exobiology [now astrobiology]. As much as I wanted to believe 84001 contained Martian microfossils, I was never convinced.

Will we find more complex forms of life in the Solar System?
If life exists elsewhere in the Solar System, it is most likely microbial in nature. Micro-organisms and the communities that they form can be complex, but I do not think that macro-organisms or intelligent life evolved in the Solar System. Micro-organisms can harbour and manipulate small niches on planets. Larger organisms need a larger environment for support. Most environments we have observed beyond Earth do not seem conducive to supporting the physics and chemistry of macro-life forms.

What future astrobiological missions could be of most interest?
Of all the places for us to explore for possible past or present extraterrestrial life, Mars offers our best opportunity to find it. It's close and the environments are similar enough to Earth's that we can figure out how to best explore them. Exploring extremely unfamiliar environments is equally important to astrobiology. Venus, Titan, Europa and other bodies in the Solar System have conditions that are so different from Earth's that they challenge us to think outside of the box, which will also provide us with an observational baseline for exoplanet comparison.

Which do you think will be first to find signs of extraterrestrial life: robotic exploration, planet hunting or signal detection (SETI)?
I think robotic exploration poses our best chance of observing signs of extraterrestrial life since most life beyond Earth is probably microbial, if it exists.

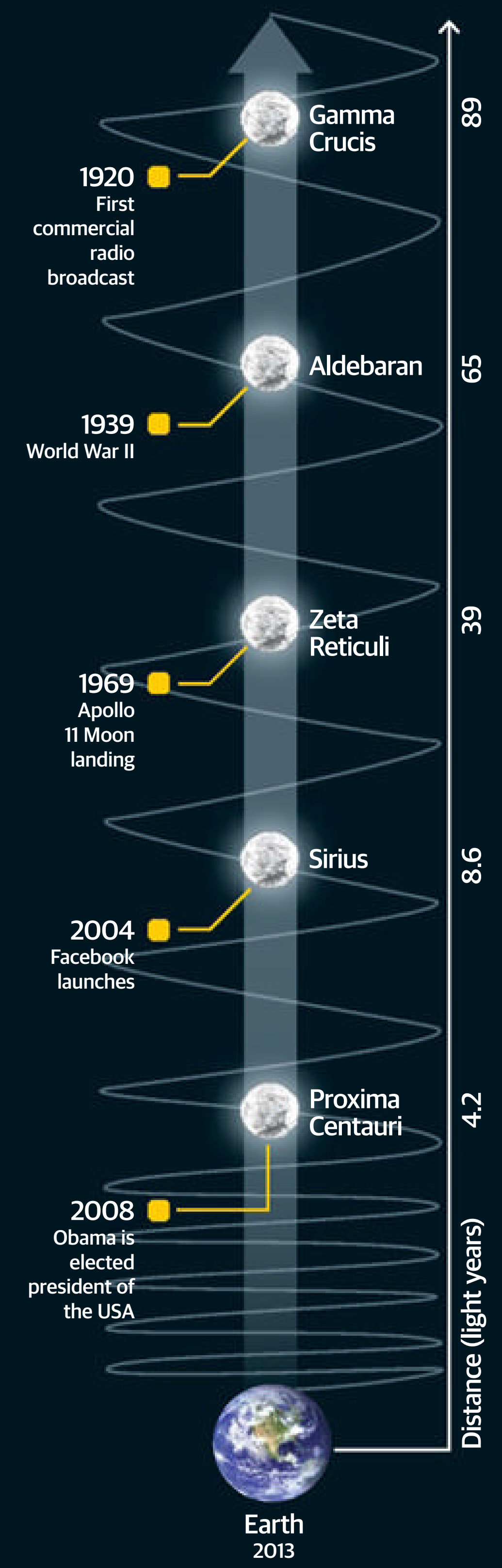
BIO

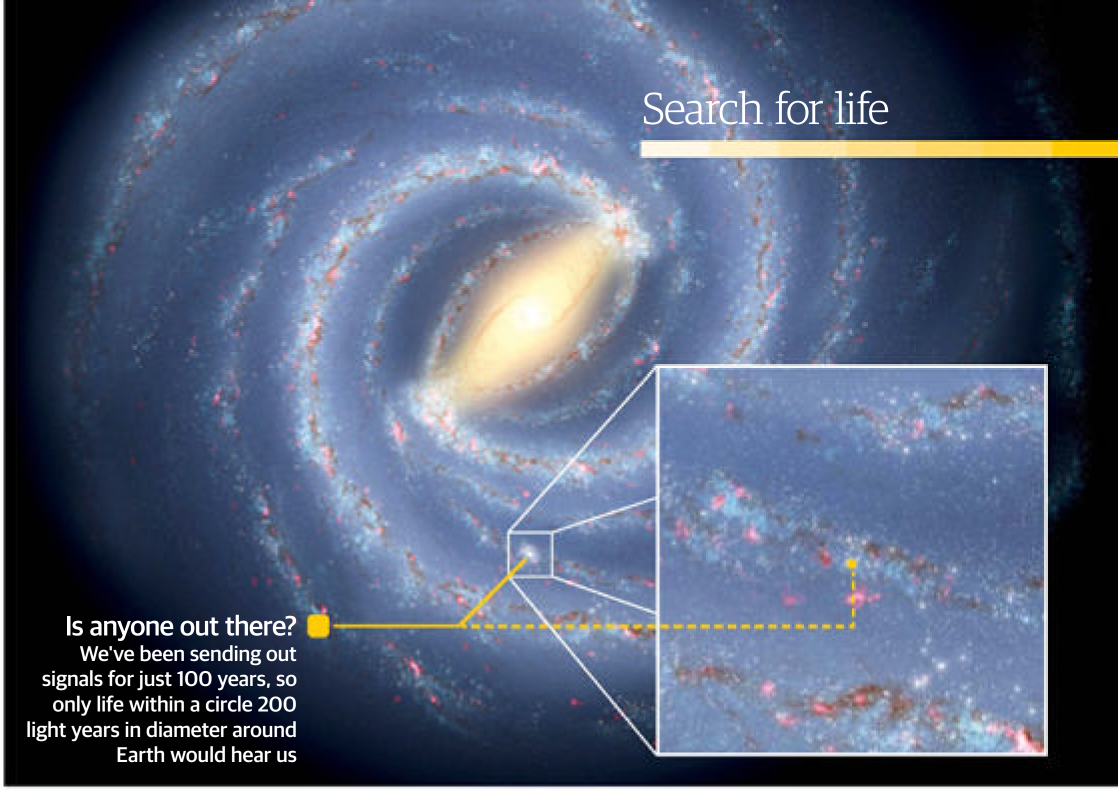
Dr Jennifer Eigenbrode
Dr Eigenbrode is a research scientist at NASA Goddard Space Flight Center, who specialises in astrobiology. She is also a participating scientist on the Mars Science Laboratory mission.

> "Robotic exploration poses our best chance of observing signs of extraterrestrial life"

Interstellar broadcasts

For the past 100 years we've been broadcasting our position to the rest of the galaxy, but how far have our signals actually reached?





Is anyone out there? We've been sending out signals for just 100 years, so only life within a circle 200 light years in diameter around Earth would hear us

their atmosphere, a vital clue in discerning whether they are habitable or not. Groundbreaking research into the possibility of measuring the atmospheres of exoplanets for signs of methane, oxygen and other elements, or even looking for signs of artificial lights (just as we can see the Earth at night from space) will bring us closer to finding alien civilisations.

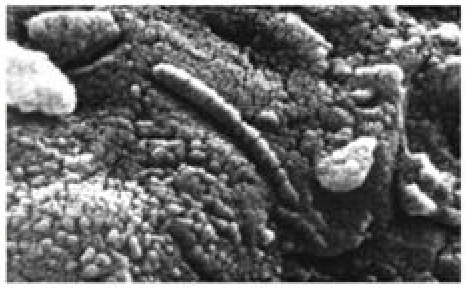
While we're searching for alien life, however, could it be possible that other extraterrestrial races are also doing the same thing? We've been broadcasting our position, both intentionally and unintentionally, by emitting radio waves for about a century. If anyone is within 100 light years of Earth, they will be able to hear us. In fact, in 1974 we sent out something called the Arecibo message, a broadcast of radio waves that, for the first time, contained data about humanity that could be interpreted by an alien race and understood to be a call from our civilisation to theirs. It's not inconceivable to think that other races might have done the same thing; maybe there are thousands of Arecibo messages streaming through the galaxy, but we just haven't come across one yet.

With all this talk of exoplanets, habitable worlds and aliens, however, you might be forgiven for having one question burning in your mind; if there really is intelligent life out there, then where is everyone? You're not alone in thinking this. Way back in 1950, astrophysicist Enrico Fermi asked this very question, which became known as the Fermi paradox. He argued that because the galaxy isn't teeming with spacecraft, or that we've never been sent a message from aliens, then either interstellar travel must be impossible (therefore dashing our hopes of ever exploring the galaxy) or we are the only intelligent civilisation in the universe.

There are a number of explanations as to why this is so, but the most plausible relates to the history of a planet like Earth. Our planet is 4.6 billion years old, but only in the last several hundred million years has it been inhabited by sophisticated organisms. Only in the last several thousand years has intelligent and sentient life, namely humans, made its mark on the globe. And only in the past one hundred years have we seriously begun observing and exploring the cosmos, and also sending out signals of our own. Humanity won't be around forever; an extinction event, either natural or man-made, could cut short

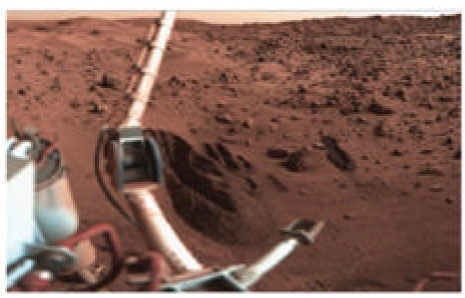
Have we already found life?

There have been several instances where controversial evidence suggested that we may have already found life elsewhere in the universe



Allan Hills 84001

In Antarctica on 27 December 1984, a team of American scientists found a meteorite named Allan Hills 84001 (ALH 84001) that shot to fame 12 years later when it was announced that it might contain microscopic fossils of Martian bacteria. However, no conclusive evidence could prove whether this was so.



The Viking probes

In 1976, NASA landed two probes on Mars, Viking 1 and 2, which had instruments to perform biological experiments on the surface. Controversy surrounded the results; early indications suggested they'd found evidence of organic compounds, but some claimed that the nature of the experiment, which heated soil samples, would have destroyed organics, suggesting the results were erroneous.

Translating an alien language

Dr John Elliott

BIO

Dr John Elliott
Dr Elliott is a Reader in Intelligence Engineering at Leeds Metropolitan University in the UK. He has been involved with SETI since 1999, and his research includes the post detection decipherment of an extraterrestrial signal.

What work do you do for SETI?
My contributions in the academic side are in being able to understand the structures in the signal if we receive one. There's been at least one occasion where I've looked at a signal, just to see if there's any structure in there. So if they pick something up, I'll be looking at the content to see if there's anything in there that denotes intelligence, any sort of linguistic phenomena or imagery or anything with structure that's actually conveying information.

How confident are you that you could decipher the message?
It obviously all depends on the amount of content you've got. If it was just a short burst, like the Wow! signal, then you're up against it. But if it was someone on the other end broadcasting an encyclopedia, then you've got a great chance of deciphering it. And if there's a crib [key] attached to it then you've got some way to unlock it or decipher it. If it's something very simple but with enough information then you could start to pick it apart and be able to have a good guess at what they are saying like "hello", "we are here", this sort of thing.

Would you respond to their message?
The flip side of all this is message construction. Because of the nature of the deciphering side I'm sort of one of the main people that deals with the message construction because one is relevant to the other. Constructing a message is a big debate for SETI, it splits us down the centre. Should we send a message back? Many of us, me included, are in the camp that, yes, for God's sake, they're going to be huge distances away from us, let's just try to communicate!

What would we say to them?
The obvious thing is to copy what they've sent back to them with something of our own included. There are some people that send messages [without consent] anyway. People are sending messages purposefully out from Earth, and that's an issue. While we are debating whether to send a message, some people are already sending them. You'll end up in the hands of amateurs there if you don't watch it.

Will we ever find a signal?
Yes. There's a huge universe, at least ten to the power of 21 stars out there, and there's at least that number of planets. We've only just started searching the sky. Our ability to listen to the universe is exponentially growing. There are so many planets out there in habitable regions that, just through the power of measuring probability, life has got to be out there. I can't think of a sensible argument that would say it isn't. I wouldn't mind putting money on it, although I might not be around by the time they find it! But I think they will.

> "I'll be looking at the content to see if there's anything in there that denotes intelligence"

Get involved with SETI

If you're interested in becoming an alien hunter, then there's never been a better time to get involved with the SETI Institute. Head over to the website at www.seti.org to find out more.

You can also sign up for SETI@Home, a piece of software that runs in the background on your computer and makes use of processing power that is otherwise unused.

our ambitions to continue exploring. That would mean that an intelligent civilisation has only a brief period to make a mark in the lifetime of their planet. If we're going to find one, we're going to need to continue our extensive search, as it may be that every habitable planet has only a comparatively brief window in which intelligent life thrives.

However, searching for intelligent extraterrestrial life isn't the only hunt currently on the go. As mentioned earlier, our robotic exploration of the Solar System is looking at the possibility of microbial life residing on the surface of Mars, or perhaps one of the potentially habitable moons such as Europa, Ganymede or Titan. From landers to orbiters to probes, we've barely scratched the surface of the secrets some of the other destinations in our Solar System might be hiding.

In the mid-Seventies, NASA conducted the first astrobiology experiment outside of Earth, sending its Viking 1 and 2 landers to Mars to dig into the soil and look for signs of past or present life on the Red Planet. The results proved to be inconclusive but they sparked a hunger to learn more; right now, the Curiosity rover is making its way across the Martian surface to answer the very same question. And even here on Earth, research is proving useful. We've found life in the deepest, darkest and coldest places, whether it's at the bottom of a frozen lake or in highly acidic environments. Research like this could help us to one day look for life on frozen worlds like Europa or liquid-bearing places like Titan. In this regard, astrobiologists are hopeful of one day discovering microbial life.

Therefore, in our continued hunt to prove that Earth is just one world where life has made a mark in the universe, it will be down to the work of various people around the globe to make the vital discoveries that could indicate the presence of intelligent or basic life elsewhere. Whether it's experts at NASA working on a high-profile, next-generation planet-hunting machine such as the James Webb Space Telescope, or it's the valiant workers who are looking for signals outside of our Solar System at SETI, or even the astrobiologists searching for bacteria on another world, these dedicated people will continue to work towards finding alien life. They are convinced we are not alone in this universe and they aim to prove it, one way or another.

5 amazing facts about
Rockets

The first rocket landed in a cabbage patch

The first-ever liquid-fuelled rocket was launched by American Robert Goddard on 16 March 1926, although the Chinese used solid-fuel rockets a thousand years prior. Goddard's rocket climbed 12.5m (41ft) before crashing in a cabbage patch. However, he was widely derided for suggesting a rocket could one day take humans to the Moon.

The Saturn V was heavier than 400 elephants

Coming in at a massive 2.8 million kg (6.2 million lb), the Saturn V is the most powerful rocket to have ever been launched. It was as tall as a 36-storey building and could take the equivalent of ten school buses into Earth orbit, while the amount of fuel it used could have driven a car around the world 800 times.

Paint designs keep track of rockets

Many rockets use different paint styles so ground controllers can track their motion, roll and orientation. The iconic Saturn V used chequered paint for this purpose, as did the early Redstone and Titan rockets. Modern rockets use the External Vehicle Markings (EVM) Document, which outlines a function for each paint marking.

The fastest rocket ever approached Mach 50

The quickest rocket to ever be launched was a five-booster configuration Atlas V on 19 January 2006. It carried the New Horizons spacecraft, which is currently on its way to Pluto, and reached over 58,000km/h (36,000mph). At this speed it got to the Moon's orbit in just nine hours, compared to the three-day journey time for Apollo astronauts.

Russia has launched the most rockets

As of December 2011, 50.5% of all spacecraft launches (3,595) were carried out by Russia. Of the 7,120 spacecraft launched, the USA is responsible for 1,857 (26.1%), while Europe's count is at 338 (4.8%). Since the dawn of the space age in 1957 the busiest year for rockets so far was 1965, when 180 spacecraft were launched.

Space delivery service

400 kilometre-high postage: a same-day delivery system for sending kit from the International Space Station back to Earth

Intuitive Machines, a commercial technology company, in cooperation with NASA, is producing the Terrestrial Return Vehicle (TRV) that will quickly return lab experiments and other perishable materials or time-critical material from space to Earth. Scheduled for deployment in 2016, it will fill a pressing need to carry out exciting new experiments and provide a regular delivery of samples from the International Space Station to Earth. At the moment it is frustrating that these materials can only be sent back a couple of times a year and require a long-winded planning procedure.

The project is managed by the Center for the Advancement of Science in Space (CASIS), which will be responsible for sending the TRVs to the ISS on commercial resupply service vehicles, their in-orbit operations and for their non-flight systems.

Intuitive Machines will design the vehicles, obtain certification for their flight worthiness and organise the recovery and delivery of the payloads to terrestrial laboratories within 24 hours of their departure from the ISS.

The TRV, besides being more convenient, will be cheaper to operate than the large Dragon capsules that are currently used for ISS cargo transfers. They are small enough for several to be sent, stored and used on board the ISS at the same time.

The craft itself looks like a miniature wing-less Space Shuttle. At only about one metre (3.3 feet) long and half a metre (1.6 feet) wide, it is roughly the size of a set of golf clubs. It will carry a payload of five to ten kilograms (11 to 22 pounds) in a space of 30 litres (eight gallons), and to preserve samples the TRV can be configured to carry cold storage compartments. Future TRV craft will also be developed to carry live mice and other small animals.

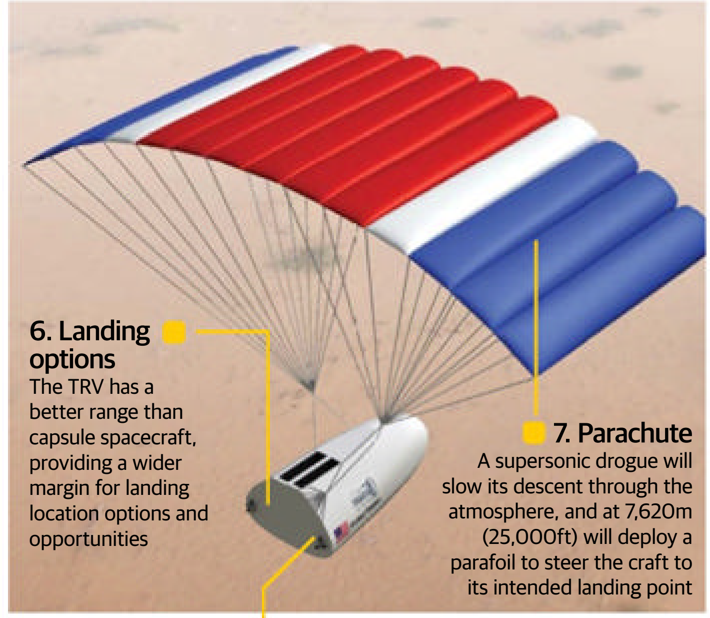
When experimental samples are ready to be sent back to Earth, they are loaded inside a TRV. It is then transferred to the Japanese Experiment Module (JEM) airlock. On exit from the airlock the TRV is grabbed by the JEM Remote Manipulator System arm, which moves it away from the ISS and releases it when at the correct attitude.

The TRV has its own engines that are powered by warm nitrogen gas at high pressure. The main engine is fired to initiate the re-entry into the Earth's atmosphere, and it uses attitude control jets to guide it accurately toward our planet.

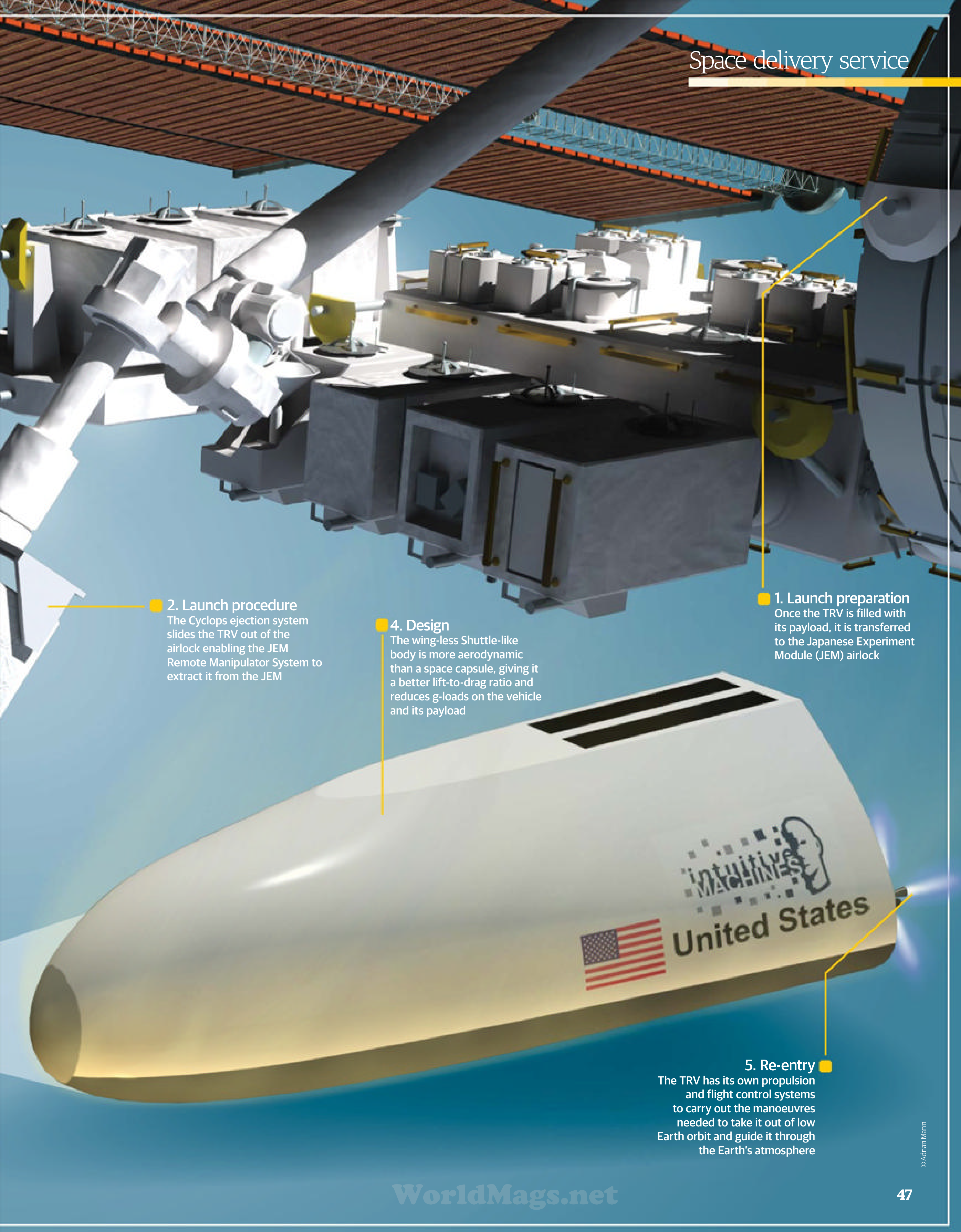
The first TRV landings will be made on a dry lake bed in the Utah desert in the United States. Since it has a lifting body-type aeroshape and a steerable parafoil to guide it through the Earth's lower atmosphere, it is anticipated that in future it will be able to provide a very accurate and flexible range of landing options.

The type of experiments that will benefit from this rapid delivery service range from the study of protein crystal formation to the growth of human tissue. In the microgravity of the ISS crystals are able to grow larger and in all directions, which is extremely useful for pharmaceutical research and development. Similarly, in microgravity samples of human tissue are able to form in three dimensions, whereas on Earth they grow flat due to the effects of gravity. This type of research can provide insights into the growth of cancerous and normal tissues, and facilitate the testing of new drugs.

By getting quick feedback, scientists can use the data for further experiments, more efficiently exploring new areas of study. In essence, the small TRV will have a big impact on the range and type of research conducted on the ISS.



> "The TRV will have a big impact on the type of research conducted on the ISS"


1. Launch preparation
Once the TRV is filled with its payload, it is transferred to the Japanese Experiment Module (JEM) airlock
2. Launch procedure
The Cyclops ejection system slides the TRV out of the airlock enabling the JEM Remote Manipulator System to extract it from the JEM
4. Design
The wing-less Shuttle-like body is more aerodynamic than a space capsule, giving it a better lift-to-drag ratio and reduces g-loads on the vehicle and its payload
intuitive MACHINES
United States
5. Re-entry
The TRV has its own propulsion and flight control systems to carry out the manoeuvres needed to take it out of low Earth orbit and guide it through the Earth's atmosphere

Underwater space training

How astronauts are prepared for danger-filled space missions in NASA's Neutral Buoyancy Lab

Training for the weightlessness of space is a major undertaking on NASA's part that requires a dedicated test facility and a battery of cutting-edge equipment. As zero gravity freefall on a specially adapted flight isn't practical for long training periods and anti-gravity 'machines' are set to remain the stuff of science fiction, NASA uses the 23.5-million-litre (6.2-million-gallon) giant swimming pool at its Neutral Buoyancy Lab in Houston, Texas.

Neutral buoyancy itself is a property of an object that gives it an equal tendency to float to the surface as it does to sink to the bottom, so that it appears to hover in the same place in water. This property of neutral buoyancy is very similar to the weightlessness endowed by the lack of gravity in space: an astronaut wearing a neutral buoyancy suit in the pool is easily manipulated, just like they would be in space, but there are some key differences. The water drags on the astronaut to make movement and certain actions (like keeping an object still) more difficult than it would be in space, while making it easier to set an object in motion. The other problem is that astronauts aren't truly weightless and can still feel the weight of their bodies while in the suit. For both these reasons, performing any tasks slowly and an awareness of the NBL pool can help minimise these limitations.

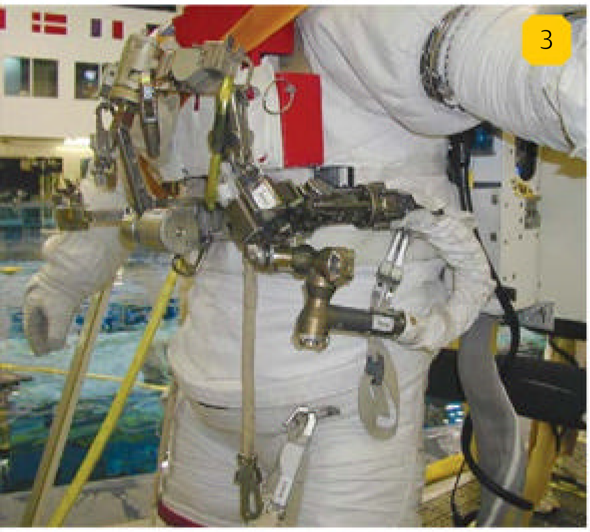
The 12.2-metre (40-foot) deep pool is primarily used for extra-vehicular activity (EVA) training. Astronauts, particularly those embarking on a mission to the International Space Station, practice full spacewalks lasting five hours at a time, manipulating objects and moving around large-scale mock-ups of the craft they will be working on. The fully completed ISS, at 107 x 73 metres (350 x 240 feet), wouldn't fit inside the NBL's 62 x 31 metre (202 x 102 feet) pool, but smaller replicas of the module the astronauts will work on are effective enough to train with. The current standard for NASA is that astronauts, depending on the difficulty of the EVA, spend five to seven times the amount of time training in the NBL as they would for the actual EVA.

The suits each astronaut wears for the NBL pool are very similar to those used on an EVA. Many of the suit components have, in fact, been salvaged from spacesuits that have already seen some EVA action in orbit on the ISS. Apart from the addition of weights and floats to give the suit with its wearer inside the property of being neutrally buoyant while in the water, NBL suits are distinguished by their life support and environmental control systems. These are self-contained with space EVA suits but while training in the pool, they're provided by an umbilical cord attached to an external machine that supplies electricity, water coolant and pressurised breathing gas.

Naturally, safety and the health of the astronauts-in-training is carefully observed while in the pool. Although the dives aren't particularly deep (12 metres/40 feet, while deep for a swimming pool is considered a shallow dive) they are for long periods of time. So the NBL has a full complement of medical staff on hand consisting of two physicians, two paramedics and 12 physiology personnel. The NBL also has a hyperbaric chamber on-site to treat any diver suffering from decompression sickness – otherwise known as 'the bends'.


Astronauts Terry Virts (NASA) and Samantha Cristoforetti (ESA) in training for ISS expedition 42/43, with divers to assist them in the EVA rehearsal

The biggest space camera



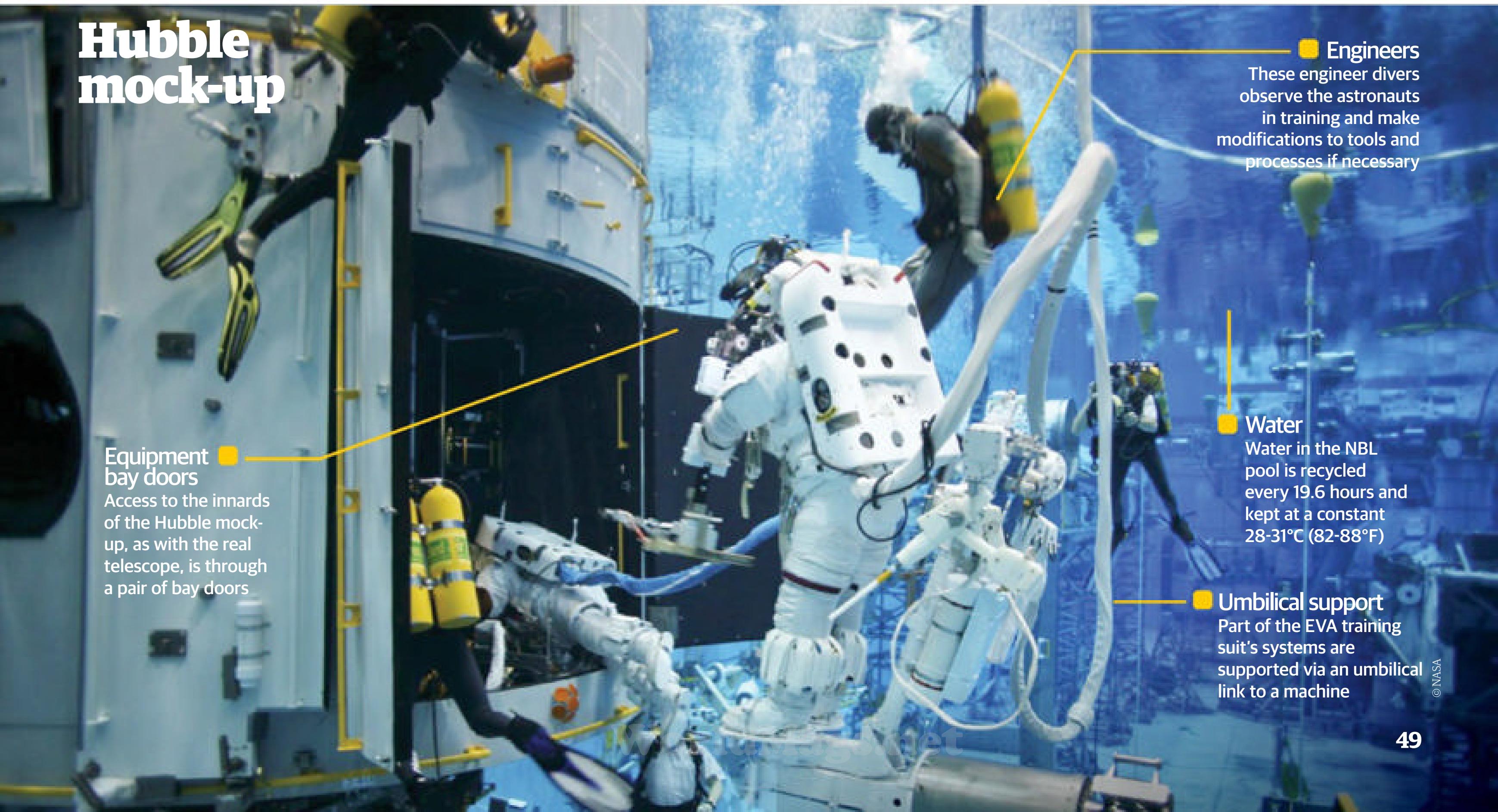
1. Orion model
A model of the Orion spacecraft is lowered into the NBL pool to test its behaviour in water.

2. EVA training
ESA astronaut Pedro Duque trains with a partner in a basic mission specialist session.

3. Rig
Tools and anchors are attached to the front of the astronaut's rig for easier access.

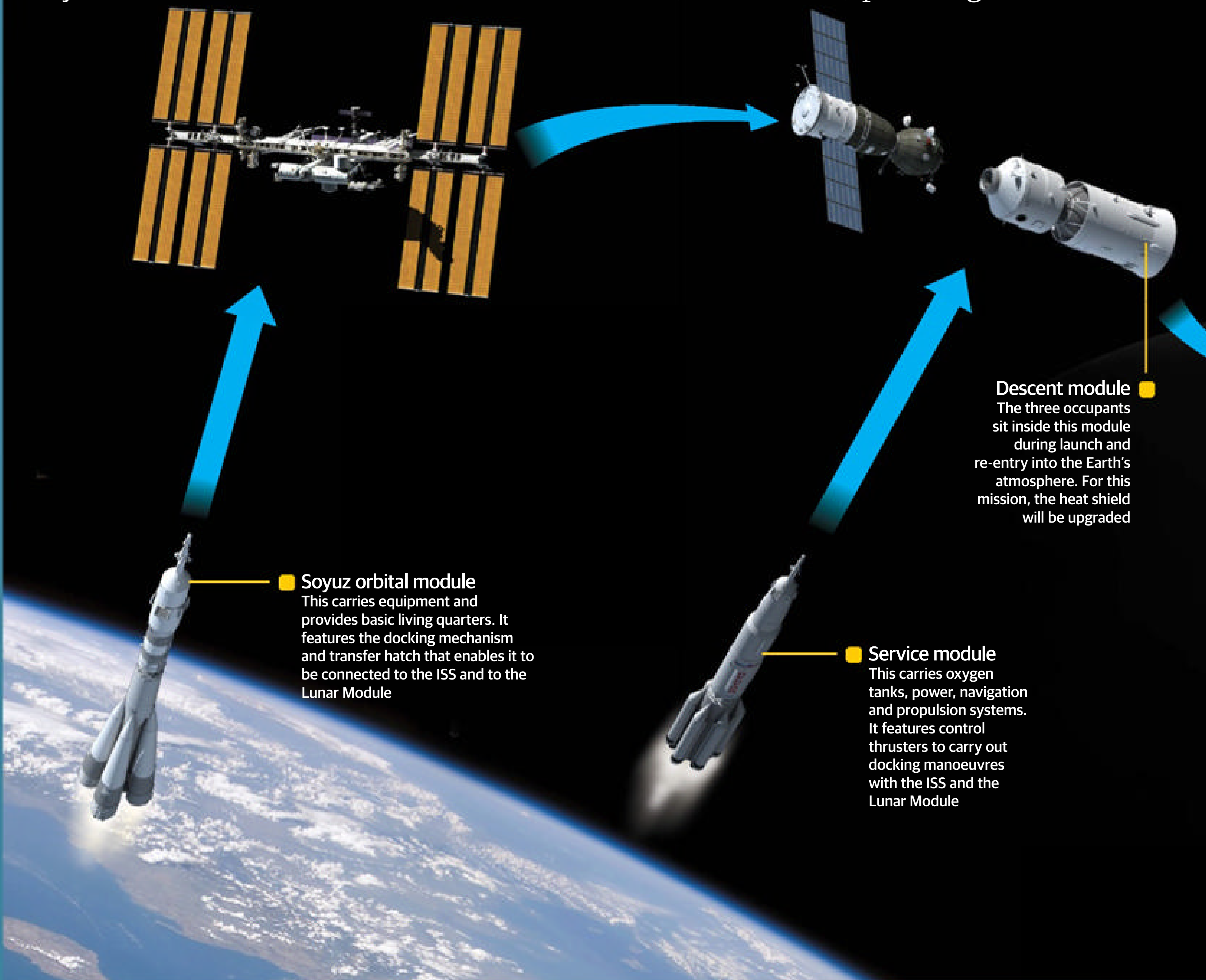
4. Diver assist
One of the technician divers helps an astronaut manoeuvre into position.

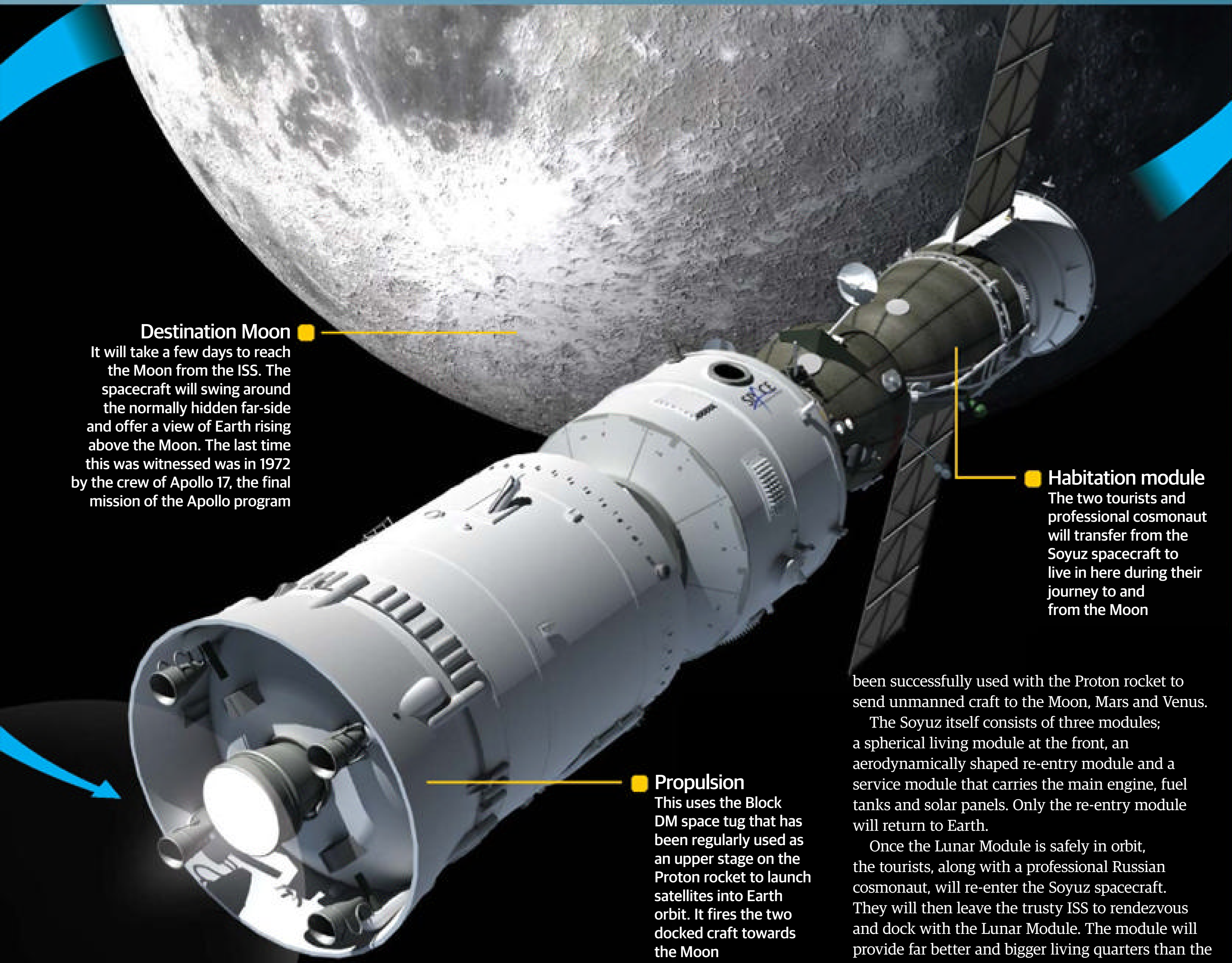
5. Commander training
ISS expedition 22 commander Jeffrey Williams in the NBL pool during training.



Millionaire Moon tourism

Fancy a trip around the Moon? That's what Space Adventures is offering to anyone who is able to afford the $150 million (£90 million) price tag





Multi-million and billionaires can book their flight around the Moon for as early as 2018, using Space Adventures' imaginative use of existing spacecraft and technology. An essential cornerstone of this project are the Soyuz rockets, spacecraft that were originally designed to take cosmonauts to the Moon. They didn't achieve that goal, but in the Sixties and Seventies they were easily adapted to ferry cosmonauts and astronauts into Earth orbit and to space stations. In the decades since the demise of the Space Shuttle, the Soyuz craft has become the world's safest and most cost-effective spacecraft.

Each trip to the Moon will carry two tourists, who will spend at least eight months preparing themselves for the high G-forces of lift-off and the weightlessness of space, along with training in operating the Soyuz module, collecting data and conducting experiments. They will blast off from the Baikonur Cosmodrome in Kazakhstan, and dock with the ISS, where they will stay for ten days. While there, they will become acclimatised to living in space, carrying out a few observations and experiments. Meanwhile, a Proton rocket will blast off from Earth to deliver a Lunar Module into low Earth orbit. This unmanned craft will consist of a living module and a Block DM propulsion stage.

The Proton rocket and Block DM are other blasts from the Soviet past. The Proton rocket was originally designed as an intercontinental ballistic missile, but the plans changed in the hope that it could be used to send cosmonauts around the Moon before the Apollo program. Since then it has been regularly used to launch satellites into Earth orbit.

The Block DM was developed as the upper stage for rockets taking unmanned craft to the Moon. The 5.5-metre (18-foot)-long, four-metre (13-foot)-diameter space tug has a main engine that can be fired several times over a multi-day mission. It has been successfully used with the Proton rocket to send unmanned craft to the Moon, Mars and Venus.

The Soyuz itself consists of three modules; a spherical living module at the front, an aerodynamically shaped re-entry module and a service module that carries the main engine, fuel tanks and solar panels. Only the re-entry module will return to Earth.

Once the Lunar Module is safely in orbit, the tourists, along with a professional Russian cosmonaut, will re-enter the Soyuz spacecraft. They will then leave the trusty ISS to rendezvous and dock with the Lunar Module. The module will provide far better and bigger living quarters than the Soyuz, and the Block DM engine will send the two docked craft in a trajectory around the Moon and back to Earth. The circumlunar flight will take them within 100 kilometres (62 miles) of the lunar surface and they will enjoy the sight of the normally hidden far-side of the Moon. Not only that, they will also get a spectacular view of planet Earth rising above the surface of the Moon. This part of their space vacation will last six days and culminate with it jettisoning the Lunar Module and returning to Earth inside the Soyuz spacecraft. The Soyuz capsule communications and navigation systems will be upgraded, and it will need a different heat shield, as the craft will re-enter the Earth's atmosphere at a greater speed than if it was merely returning from Earth orbit. By skipping the Soyuz through the atmosphere, its will slow enough for it to make a parachute landing to the ground. If there is sufficient demand, Energia and Space Adventures will launch a series of expeditions to the Moon.

INTERSTELLAR SPACE TRAVEL

The science behind the warp drives that could take us to the stars

To date, mankind has managed to send just one object beyond the boundary of our own Solar System. Voyager 1 received gravity assists from both Jupiter and Saturn that boosted its speed to over 61,000 kilometres (38,000 miles) per hour, but it still took 35 years to spiral outwards into interstellar space, 20 billion kilometres (12 billion miles) away. At this speed, Voyager 1 would take another 75,000 years to reach our nearest star, Proxima Centauri.

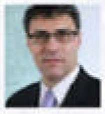
That's because 61,000 kilometres (38,000 miles) per hour is actually very slow. It's just 0.005 per cent of the ultimate speed limit for the universe: the speed of light. If you drove your car at the same fraction of the motorway speed limit, you would be travelling ten times slower than a snail. Clearly, we are never going to explore beyond our own Solar System so long as we continue travelling at the speed of our current probes. Even at the speed of light, the universe is still far too massive for us to comfortably explore. It would take more than 100,000 years to cross our galaxy, 2.5 million years to reach the next one, and 45 billion years to reach the edge of the known universe. What we need is some way to travel faster than the speed of light. The problem is that Einstein said this is impossible.

Here's the reason: Einstein's law of special relativity says that the speed of light (referred to by the letter 'c') is always constant, no matter where you are in the universe or how fast you are moving. If you shine a torch out of the front window of a spaceship that is travelling at half the speed of light (0.5c), that beam travels away from you at 1c. An observer, however, hovering in space as you zoom past would also see the beam travelling forward at the speed of light, not 1.5c as you might expect. And if you shine it out of the rear window, both of you will still see the beam travelling at 1c. This is because relative velocities don't just add together in a simple way. It only seems that way to us on Earth because it's an approximation that works at low speeds. The faster you go, the less accurate this approximation is, but the difference is only really appreciable once you go faster than about ten per cent of the speed of light (0.1c).

As a rocket fires its thrusters, it gets faster, but the amount its speed increases by for each second of thrust is less each time. The rocket could accelerate forever and still never reach the speed of light. This is why physicists say that it would take infinite energy to reach the speed of light – infinity is another way of saying 'never'. If you can't reach the speed of light, it follows that you can't ever go faster than it. This is true for any object that has mass.

Suppose we give up on exploring the universe, or even the galaxy. What if we simply settle for just travelling close to the speed of light without actually exceeding it? There are at least 50 stars within 16 light years of Earth, which would let us send a probe there and beam back the data in the same amount of time that the Voyager missions have been running. If you accelerate your probe at a constant 1G (a unit of acceleration that roughly equals ten metres [33 feet] per second squared) for two years, it would be travelling at 97 per cent of the speed of light by the end. That certainly sounds manageable, until you

The father of the warp drive



Dr Miguel Alcubierre tells us about his 1994 paper that covered warp drives and bubbles in space-time

Does general relativity permit warp bubbles for warp-drive technology?
Warp bubbles are theoretically possible in the sense that the required geometry of space-time is easy to write down. However, they are certainly not solutions in a strict sense.

What are the biggest obstacles to creating one?
1: The warp drive would require 'exotic matter', with negative-energy densities (antigravity) that – as far as we know – do not exist. It would also require some very weird distributions of momentum and stresses. 2: Even if you get your hands on negative energy and manage to manipulate it, you would need star-sized amounts of it. 3: At super-luminal speeds, the front of the warp bubble is disconnected from the centre. This means that a spaceship sitting in the centre of the bubble has no way of placing the required matter and energy at the front of the bubble. As a super-luminal warp bubble cannot be created from within, it would have to be set up in advance from the outside.

What happens to the ship if the warp bubble collides with an object while in motion?
It depends on the details of the geometry. Of course, hitting anything at a high speed is always very dangerous.

Are there other risks with manipulating space-time directly?
These are questions that can't be answered without knowledge of the properties of the negative energy, which might not even exist. It's like asking the Ancient Greek philosopher Democritus if you could use his atomic theory to build a bomb.

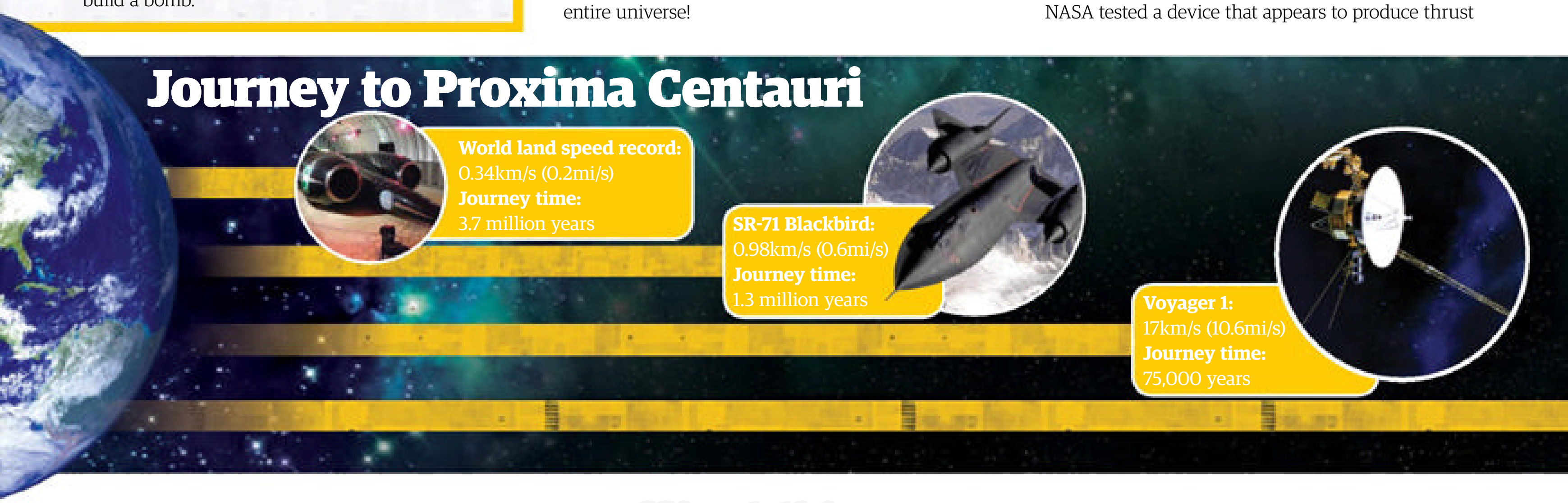
The Helix Nebula is one of the closest to Earth, but even travelling at light speed, it would take a craft 700 years to reach it. There has to be another way

consider the logistics of firing an engine for that long. The Saturn V rocket used for the Apollo missions, for example, fired its engines for less than 20 minutes total at an average acceleration of about 1.5G. In order to achieve even this short period of acceleration, the weight of the discarded stages and fuel was 60 times the weight of the spacecraft that it propelled to the Moon.

To accelerate a rocket continuously for two years, it would need a lot more fuel, but that fuel would need to be accelerated as well, which would require even more fuel and so on. This runaway cycle gets out of hand very quickly indeed. In fact, even if you only wanted to accelerate your space probe to about 0.5 per cent of the speed of light, so that it could reach Proxima Centauri in 850 years, a chemical rocket would need more hydrogen fuel than there is in the entire universe!

You could improve efficiency by switching to nuclear rockets that use fission or fusion to propel your ship with superheated streams of gas. Or, for the ultimate efficiency, you could use matter-antimatter conversion. This might drop the total amount of propellant you'd need to about ten railway tankers' full. Yet if you want the probe to slow down at the other end, you'd need to bring ten railway tankers' worth of propellant to your destination, which would increase the amount of propellant you'd need to get it there to about a thousand supertanker ships' worth of antimatter; a substance that is incredibly difficult to produce. It would take scientists at CERN an entire year to create just a billionth of a gram!

It's possible that in the future we may be able to do away with the need to carry propellant on the spaceship at all. In August 2014, a research team at NASA tested a device that appears to produce thrust

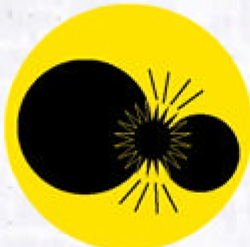


The dangers of warp travel

Even if we manage to build a warp drive, would we dare turn it on?

RADIATION

Researchers at the University of Sydney in Australia have calculated that particles and radiation could be caught up in the bow wave of a warp bubble as it travels. When the ship decelerates, the accumulated particles would be released in a devastating burst that would destroy anything in the path of the ship.

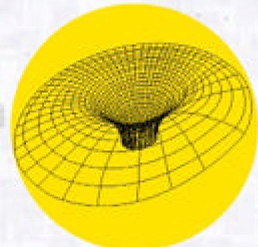


COLLISIONS

The physics of warp bubbles aren't well enough understood yet to know exactly what would happen if your course takes you through the path of a planet or star. Would it be brushed aside? Would you pass harmlessly though it? Or would you be instantly vaporised? If you fly inside the event horizon of a black hole, could you escape?

NEGATIVE ENERGY

What are the properties of negative energy? How would you store it? What happens if your negative-energy battery short-circuits? Whatever the details of the ensuing catastrophe, the numbers involved are likely to be so big that it could destroy the Solar System, never mind the spaceship.



BLACK HOLES

Even if the negative energy doesn't explode, distorting space-time so heavily could easily create a singularity, where space-time curves in on itself completely – in other words a black hole. Even if the spaceship itself escapes inside its own warp bubble, the consequences for those left behind would be disastrous.

VIOLATING CAUSALITY

In certain circumstances, travelling faster than the speed of light can enable you to travel back in time. If the universe doesn't somehow prevent this, you could create all sorts of mind-bending paradoxes, such as going back and killing the inventor of the warp drive, or your very own grandparents.

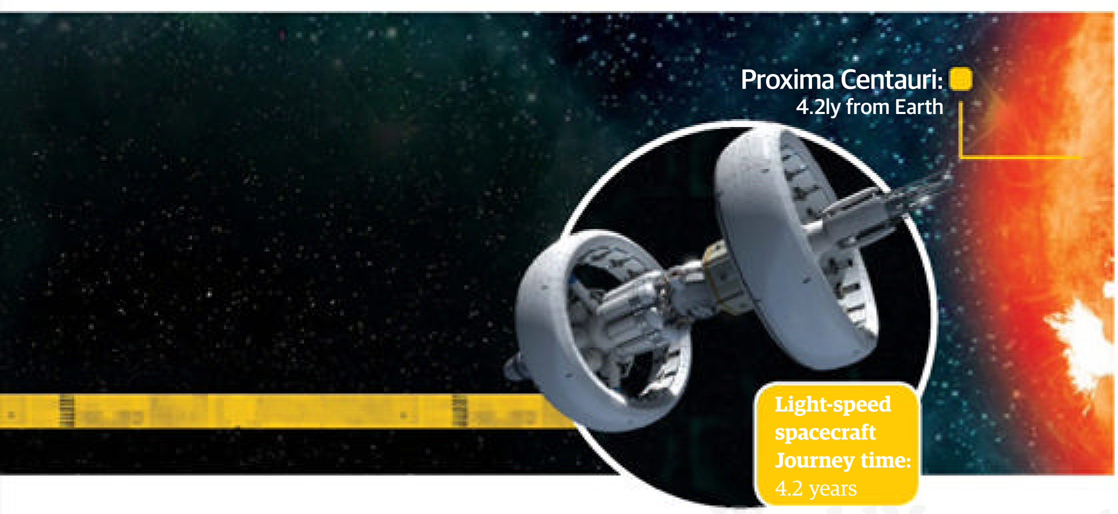
> "It's possible that in the future we may be able to do away with the need to carry propellent on the spaceship at all"

out of nowhere by bouncing microwave beams inside a closed chamber. If – and it's a big if – the results aren't due to experimental error, this device, known as the Cannae drive would appear to break a fundamental law of physics. A less speculative, propellantless propulsion system would be to use a light sail that catches a stream of photons fired from a highly-focused laser on Earth. Whichever way you do it, you still have to deliver enough kinetic energy to the spacecraft to increase its speed and even without the effort of accelerating the mass of the propellant, the energy requirement is enormous. NASA's Glenn Research Center has estimated that sending something the size of the Space Shuttle on a 50-year one-way trip to our nearest star would need 70 million trillion Joules of energy. This is equivalent to diverting the entire electricity-generating capacity of the UK full-time for all of those 50 years. However you do the sums, conventional propulsion techniques just aren't powerful enough to explore the stars.

Yet there might be a loophole. Special relativity says that no object can be accelerated to the speed of light, but it doesn't say anything about how fast space itself can move. Think of an airport travelator. You walk along it at your normal pace, but because the floor is moving as well, your total speed seems much faster to someone walking beside the travelator. We aren't adding the velocities of two objects moving on the ground; instead we are moving the very ground we walk on. Einstein's theory of general relativity showed that the three dimensions of space itself can be stretched and curved. It's a bit like a map. Maps can be flat and show places according to their positions along the width and length of the paper, or they can be globes that show them using latitude and longitude. The map is two-dimensional in both cases, but with a globe, those dimensions are curved into a third dimension. Over short distances, if the curvature is quite small, the surface of the globe will still seem flat. But if you stretch it more dramatically, some interesting things happen.

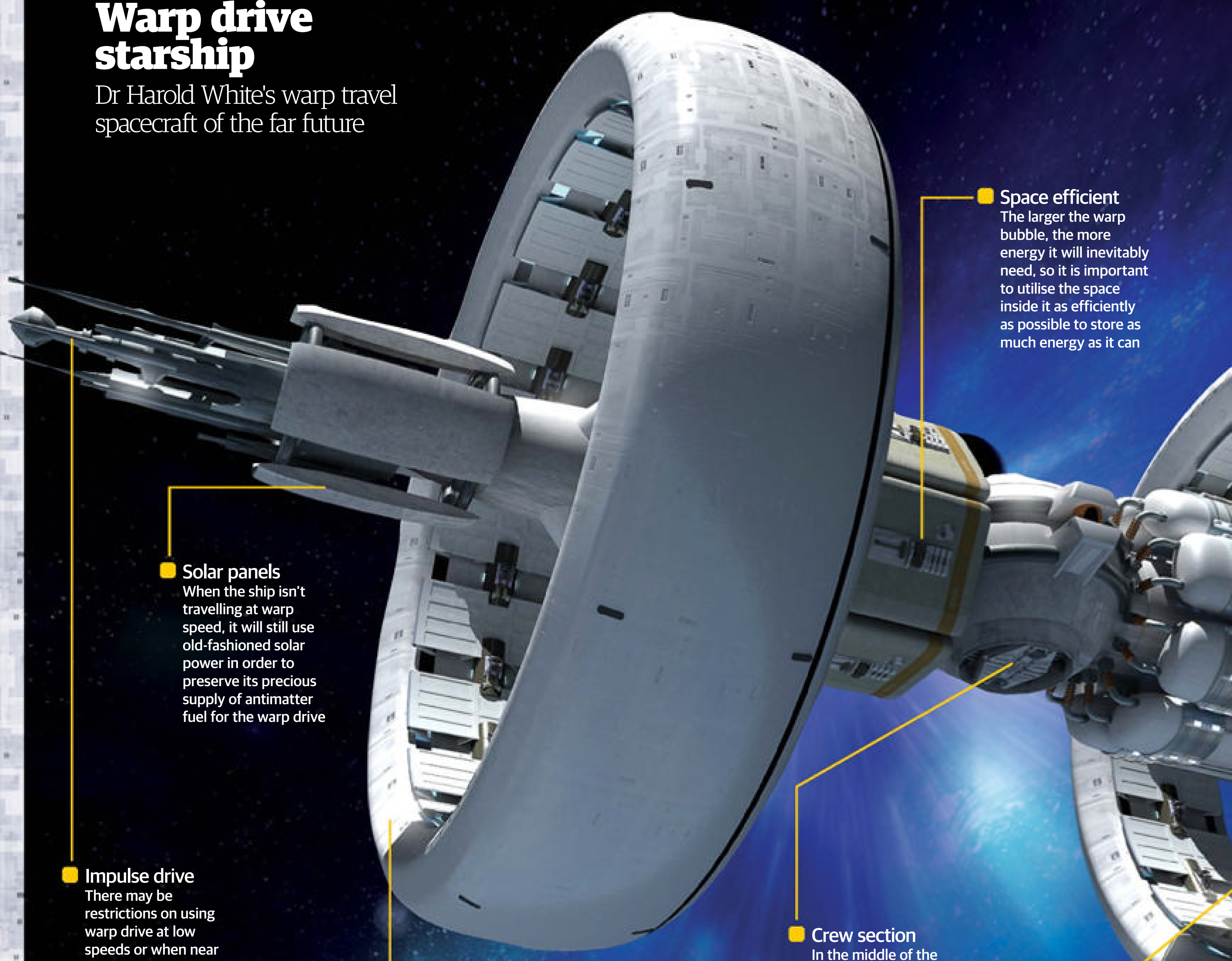
Suppose our universe globe is painted on a balloon and you push your fingers in from opposite sides so that the surface gets more and more indented. Eventually, your fingers are touching, with just the skin of the balloon between them. If you could punch through this skin without bursting the balloon, you could hop from one side of the universe to the other without travelling all the way around the outside. This form of distortion is called a wormhole.

One common objection that is raised against wormholes as a practical form of travel is that you need to position the far end where you want to go before you can travel there. If the ends of the wormhole are some kind of Stargate device, you would need to physically transport one of them there at sub-light speeds first. However, the amazing properties of wormholes could come to your rescue. A spacecraft carrying a Stargate doesn't need to bring its own fuel because you can just pipe fuel through



Warp drive starship

Dr Harold White's warp travel spacecraft of the far future



Space efficient
The larger the warp bubble, the more energy it will inevitably need, so it is important to utilise the space inside it as efficiently as possible to store as much energy as it can

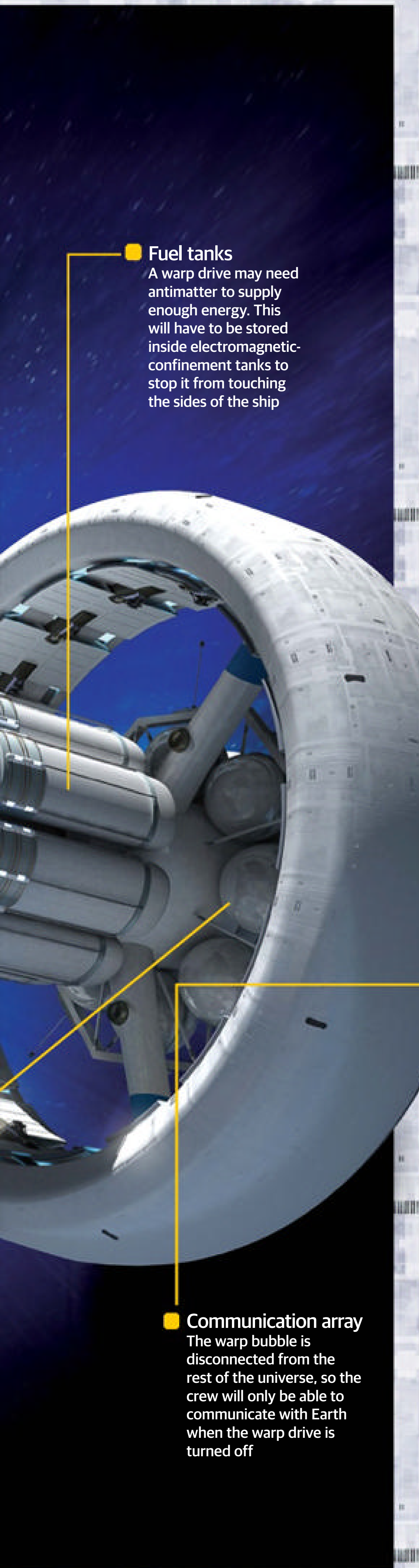
Solar panels
When the ship isn't travelling at warp speed, it will still use old-fashioned solar power in order to preserve its precious supply of antimatter fuel for the warp drive

Impulse drive
There may be restrictions on using warp drive at low speeds or when near planets, so traditional reaction jets will still be needed when it comes to manoeuvring

Crew section
In the middle of the warp bubble, space-time is perfectly flat, so the crew will experience absolutely no acceleration as they make their way between the stars

Warp rings
The energy needed to create the warp bubble is greater if the boundary of the bubble is sharp. Using thicker rings, Dr White thinks we could produce a thicker warp field

International co-operation
The resources needed to research, develop and build a warp ship will exceed the budget of any one country, so every nation will need to join in



the wormhole and have it delivered instantly, regardless of how far the ship has travelled. This doesn't violate the law of conservation of energy, because the extra mass you have supplied to the travelling ship causes the wormhole to shrink. To keep the size of the wormhole constant, you would need to pump extra energy into the device that powers it. According to professor John Cramer of the University of Washington, every kilogram (2.2 pounds) of fuel that you send through the wormhole would need 25 million megawatt-hours of extra power to keep the wormhole open. This is roughly as much electricity as the entire world produces every five weeks, so even if we diverted all our power into the Stargate, we wouldn't be able to send more than two kilograms (4.4 pounds) of fuel per month.

Imagine we have access to enough electricity to be able to pump fuel constantly through the wormhole and allow the spaceship to accelerate close to the speed of light (let's say 99.995 per cent) and we send it to Tau Ceti, a star 12 light years away. You might assume that it would be about 12 years before the spaceship would arrive and we could use our wormhole, but Einstein showed that time slows down the faster you travel.

At 99.995 per cent of the speed of light, time would pass 100 times more slowly. So for the captain of the ship, the 12-year journey would only appear to have taken 44 days. This is only true for time aboard the spaceship of course, but remember that the Stargate it carries is connected through the wormhole to the other end on Earth. Anyone looking through the wormhole would see the same view out of the front window of the spaceship as the captain sees. This means that after just 44 days they would see Tau Ceti loom into view, while Earthbound telescopes would see that the spaceship was only one per cent of the way there!

Convenient as this sounds, it raises a much bigger problem with faster-than-light travel. Ian Crawford is professor of Planetary Science and Astrobiology at Birkbeck, University of London. "With a faster-than-light drive, you can contrive situations where you would go backwards in time," he says. "And that is a big problem. If it's possible to travel faster than light then there must be some higher-order physical law that would prevent you from messing around with causality." Theoretical physicist Stephen Hawking calls this the chronology protection conjecture. "When space-time gets warped almost enough to allow travel into the past," he says, "virtual particles can almost become real particles [...] And their energy [becomes] very large. This means that the probability of these [alternative] histories is very low [...] making the world safe for historians."

So wormholes might stretch space-time to breaking point, but there are other ways to warp it that might allow us to travel faster than light, without travelling into the past. In 1994, Mexican physicist Miguel Alcubierre published a solution for the equations of general relativity that showed a way to create a bubble of distorted space-time around an object. By contracting space-time in front of a spaceship and expanding it behind, you could create a ripple in space-time that could roll across the universe, carrying the ship with it. The patch of space-time immediately surrounding the ship would be flat so the ship wouldn't actually be moving in the traditional sense, but it would be carried on the ripple of curved space-time, like a surfer riding a wave.

We don't know how to make wormholes or warp bubbles yet. All we know is that general relativity doesn't forbid them. However, the distortions that you need to travel faster than light involve bending space-time in the opposite direction to the way that gravity bends it. That suggests we would need negative matter or energy to achieve it. As exotic as that sounds, it's possible that negative energy may actually exist. If you put two metal plates in a vacuum chamber and hold them about ten nanometres apart, they will be pulled together by something called the Casimir effect. This is thought to be because even a total vacuum has some energy and the space between the plates is too small for all the possible wavelengths of this vacuum energy to fit in it. So the gap between the plates somehow has less energy that the ordinary vacuum and they are pushed together by vacuum energy on the outside surfaces. Since the energy of the vacuum is zero, by definition, this means that there is *negative* energy between the plates.

Miguel Alcubierre dismisses this form of negative energy. "Even if it exists, we have absolutely no idea how to use it for anything useful, let alone a warp drive." Professor Crawford raises an even more fundamental objection. "The Casimir effect arises out of the quantum vacuum [...] We're trying to use quantum theory to generate negative energy as a way of keeping wormholes open, which are a prediction of general relativity, and we know that we can't marry quantum theory to general relativity yet." In the same way that the theories of electricity and magnetism were eventually realised to be different aspects of the same thing (electromagnetism), theoretical physicists have been working for decades to produce a theory of quantum gravity. "When we do have a theory that reconciles general relativity and quantum theory, we don't know whether these loopholes will still be there," warns Crawford. "They might disappear once we have a more complete theory of gravity. On the other hand, a more complete theory may tell us that it's easier than we thought."

There are an estimated 10,000 times more stars in the night sky than there are grains of sand on Earth. If one per cent of them have Earth-like planets around them and one per cent of those have life and one per cent of *those* have intelligent civilisations,

"With a faster-than-light drive, you can contrive situations where you would go backwards in time" **Ian Crawford**

that's still about 10 million billion civilisations in the observable universe. If warp travel is possible, it seems even more extraordinary that we haven't been visited by any of them yet. This is known as the Fermi paradox, after physicist Enrico Fermi. One possible solution, known as the Zoo hypothesis, is that some sort of Prime Directive exists whereby spacefaring aliens all agree not to interfere with less advanced species. "The problem with the Zoo hypothesis," says Crawford, "is that it would require all of these aliens to agree to the same set of rules for the zoo."

According to Crawford, the only way this might be plausible is if warp travel is possible. "In the context of near-instantaneous travel and communication, then it becomes possible to imagine galactic political structures - Empires and Federations - that might be able to impose quarantines on planets where intelligence has just emerged. Yet it also makes it much easier to travel interstellar distances, so in fact there is a balance between galactic-scale political institutions that can force Prime Directives and the fact that there will be many more intelligent beings flying around the galaxy."

NASA's official stance on warp travel places it firmly in the realm of speculation. This doesn't mean they are ignoring it completely though. Dr Harold White at NASA's Johnson Space Center in Houston, Texas, is working on a modified version of a device called a Michelson interferometer, which will use a ring of high-voltage capacitors to induce a small warp field. If it works, it should be possible to detect it by shining a laser through the field and measuring its speed. Results so far have been inconclusive, but professor Crawford applauds the effort. "Because the physics is still just not understood, most professional physicists won't engage with it. It's just considered too speculative. So it's hats off to people like Alcubierre and Harold White and others who are sticking their heads above the parapet and pursuing the research seriously. I do think that's worth encouraging."

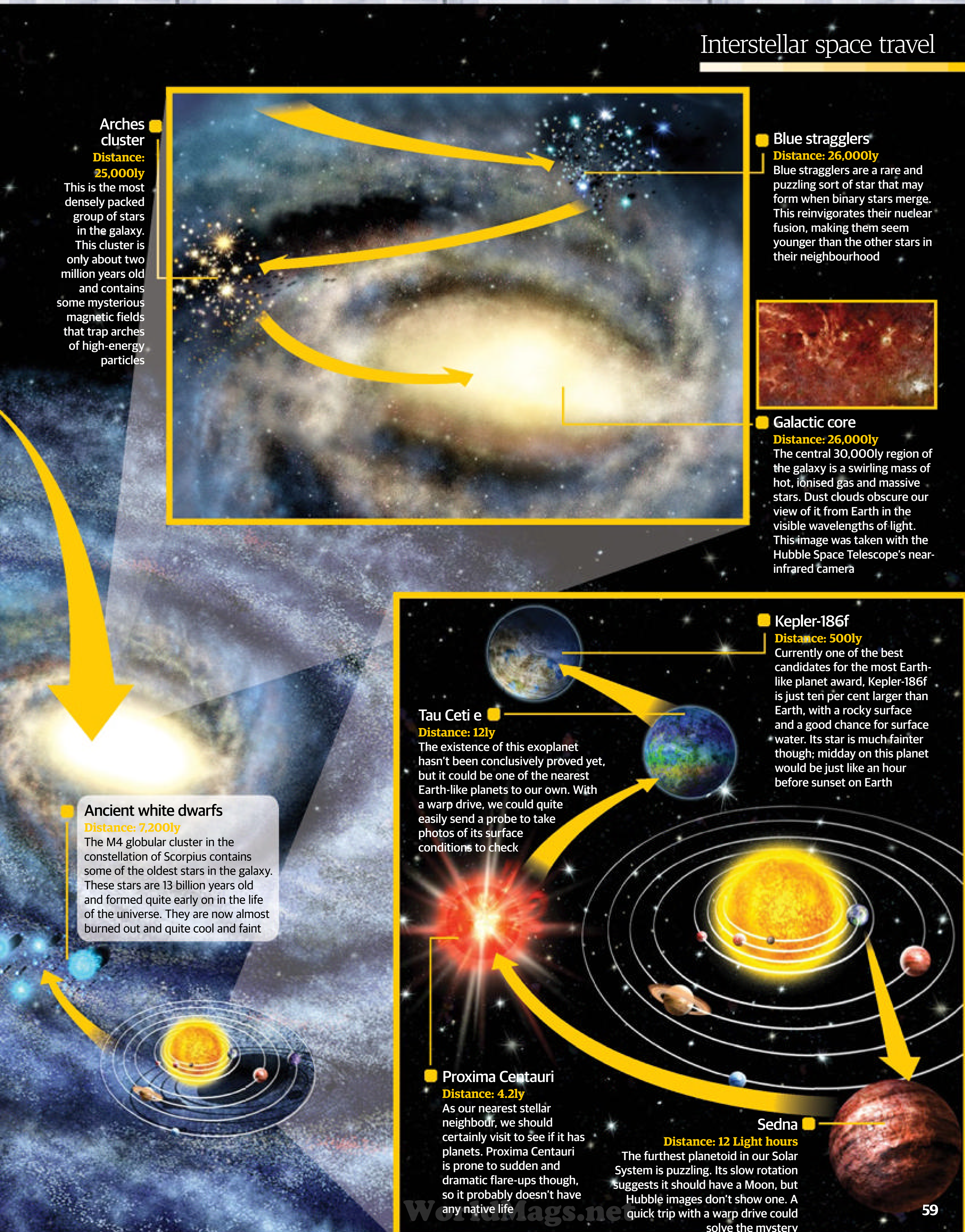
Ultimately, even if warp drives are possible, professor Crawford believes there's no guarantee that they would be any easier to build or less expensive to power than sub-light spaceships. "We don't know what's involved in building a faster-than-light probe, but we know we aren't going to wake up one morning and find that we've got it for Christmas. It's going to have to be developed, and developed from physical principles we don't understand. Interstellar space travel is really a matter of learning to walk before you can run. We have to gradually build up an industrial infrastructure within our own back yard, moving out into the Solar System, where eventually we will develop the expertise and the economic wealth that will enable us to invest some fraction of that in interstellar exploration."

Warp-drive research might seem like the philosophers' stone, the substance that could turn other metals into gold. The quest for this shortcut to riches was one that obsessed alchemists for centuries and, of course, they never found it. However, their search laid the foundations for the understanding of chemistry that we have today, which eventually gave us electricity, nuclear power and rocket fuel. So perhaps it wasn't entirely a waste of effort after all. ■

Warp-drive tourism

Unless warp drive turns out to give us infinite speed, journeys beyond our galaxy are probably still out of reach. If we could travel at 1,000 times the speed of light, however, some very interesting places in the Milky Way would suddenly become accessible.

ly = Light years



Arches cluster
Distance: 25,000ly
This is the most densely packed group of stars in the galaxy. This cluster is only about two million years old and contains some mysterious magnetic fields that trap arches of high-energy particles

Blue stragglers
Distance: 26,000ly
Blue stragglers are a rare and puzzling sort of star that may form when binary stars merge. This reinvigorates their nuclear fusion, making them seem younger than the other stars in their neighbourhood

Galactic core
Distance: 26,000ly
The central 30,000ly region of the galaxy is a swirling mass of hot, ionised gas and massive stars. Dust clouds obscure our view of it from Earth in the visible wavelengths of light. This image was taken with the Hubble Space Telescope's near-infrared camera

Kepler-186f
Distance: 500ly
Currently one of the best candidates for the most Earth-like planet award, Kepler-186f is just ten per cent larger than Earth, with a rocky surface and a good chance for surface water. Its star is much fainter though; midday on this planet would be just like an hour before sunset on Earth

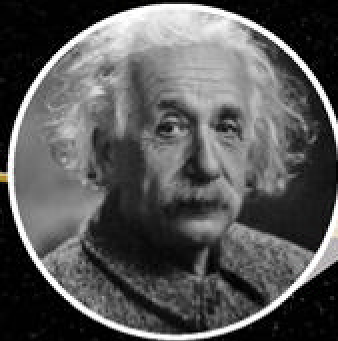
Tau Ceti e
Distance: 12ly
The existence of this exoplanet hasn't been conclusively proved yet, but it could be one of the nearest Earth-like planets to our own. With a warp drive, we could quite easily send a probe to take photos of its surface conditions to check

Ancient white dwarfs
Distance: 7,200ly
The M4 globular cluster in the constellation of Scorpius contains some of the oldest stars in the galaxy. These stars are 13 billion years old and formed quite early on in the life of the universe. They are now almost burned out and quite cool and faint

Proxima Centauri
Distance: 4.2ly
As our nearest stellar neighbour, we should certainly visit to see if it has planets. Proxima Centauri is prone to sudden and dramatic flare-ups though, so it probably doesn't have any native life

Sedna
Distance: 12 Light hours
The furthest planetoid in our Solar System is puzzling. Its slow rotation suggests it should have a Moon, but Hubble images don't show one. A quick trip with a warp drive could solve the mystery

The road to interstellar travel



1916
General relativity
Einstein shows that space and time form a complex curved shape, which is determined by the amount of energy and matter in it

1948
Casimir effect
Dutch physicist Hendrik Casimir predicts that negative energy may create a force between two metal plates. Fifty years later, this force is measured

1969
First man on the Moon

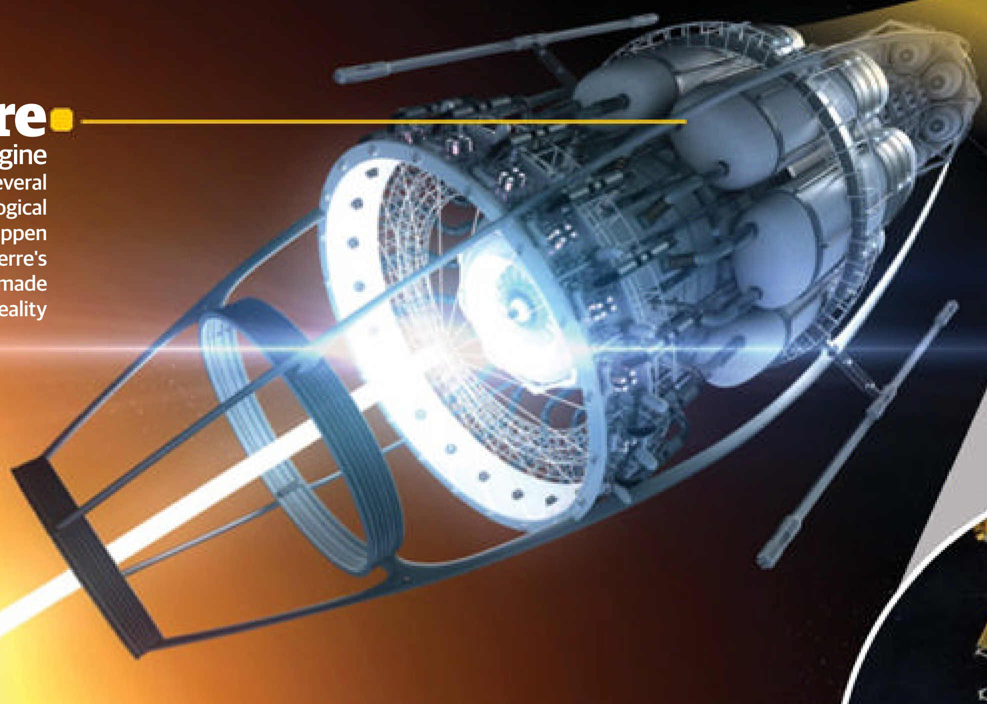
1988
Wormholes
The possibility of creating a wormhole that you could use to teleport across the universe is suggested by Kip Thorne and Mike Morris

1994
Warp bubbles
Mexican physicist Miguel Alcubierre, publishes a paper suggesting that a spaceship could travel faster than light by distorting the fabric of space-time around it

2000
First expedition to the ISS

2012
Voyager 1
The first man-made object to leave the Solar System, Voyager 1 is travelling too slowly to cross interstellar distances

Future
Warp Engine
We need several major technological advances to happen before Alcubierre's drive could be made a reality



1920 1930 1940 1950 1970 1980 1990 2000 2010

5 AMAZING FACTS ABOUT

Spacewalks

Temperatures fluctuate by up to 500 degrees

While on a spacewalk in Earth orbit the temperature changes from a balmy 120 degrees Celsius (250 degrees Fahrenheit) in sunlight to -160 degrees Celsius (-250 degrees Fahrenheit) in darkness. Spacesuits are normally white to reflect light and heat while in the Sun.

It takes hours to get ready for a spacewalk

For modern spacewalks it takes about 45 minutes to don the 125-kilogram (280-pound) suit. The astronauts must then spend an hour pre-breathing pure oxygen to adapt to the lower-pressure environment maintained in the suit before heading out of the airlock.

The first spacewalk almost ended in disaster

During humanity's first spacewalk, performed by Soviet Alexei Leonov on the Voskhod 2 mission on 18 March 1965, his suit expanded much more than had been expected and he had to leak air from his suit into space in order to get back into the spacecraft.

The longest spacewalk lasted nearly nine hours

NASA astronauts Susan Helms and Jim Voss hold the record for the longest spacewalk in history, set during the ISS Expedition 2 mission when they were outside in the vacuum of space for eight hours and 56 minutes on 11 March 2001.

There has only ever been one three-person spacewalk

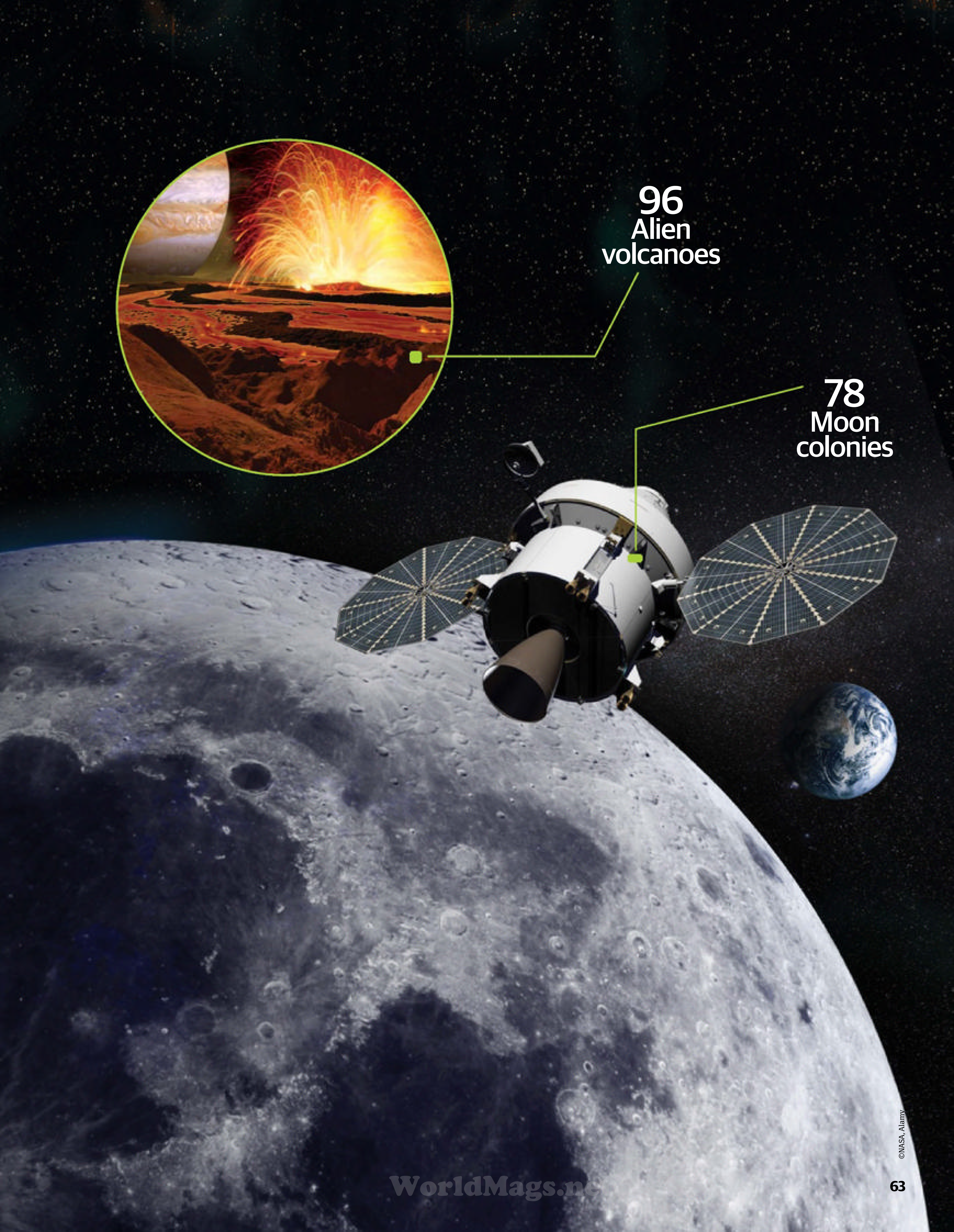
The only time three people have simultaneously exited a spacecraft to perform a spacewalk was during Space Shuttle Endeavour's STS-49 mission in May 1992. During the mission Americans Pierre Thuot, Richard Hieb and Thomas Akers captured the Intelsat VI satellite.

The STS-49 mission crew during their spacewalk

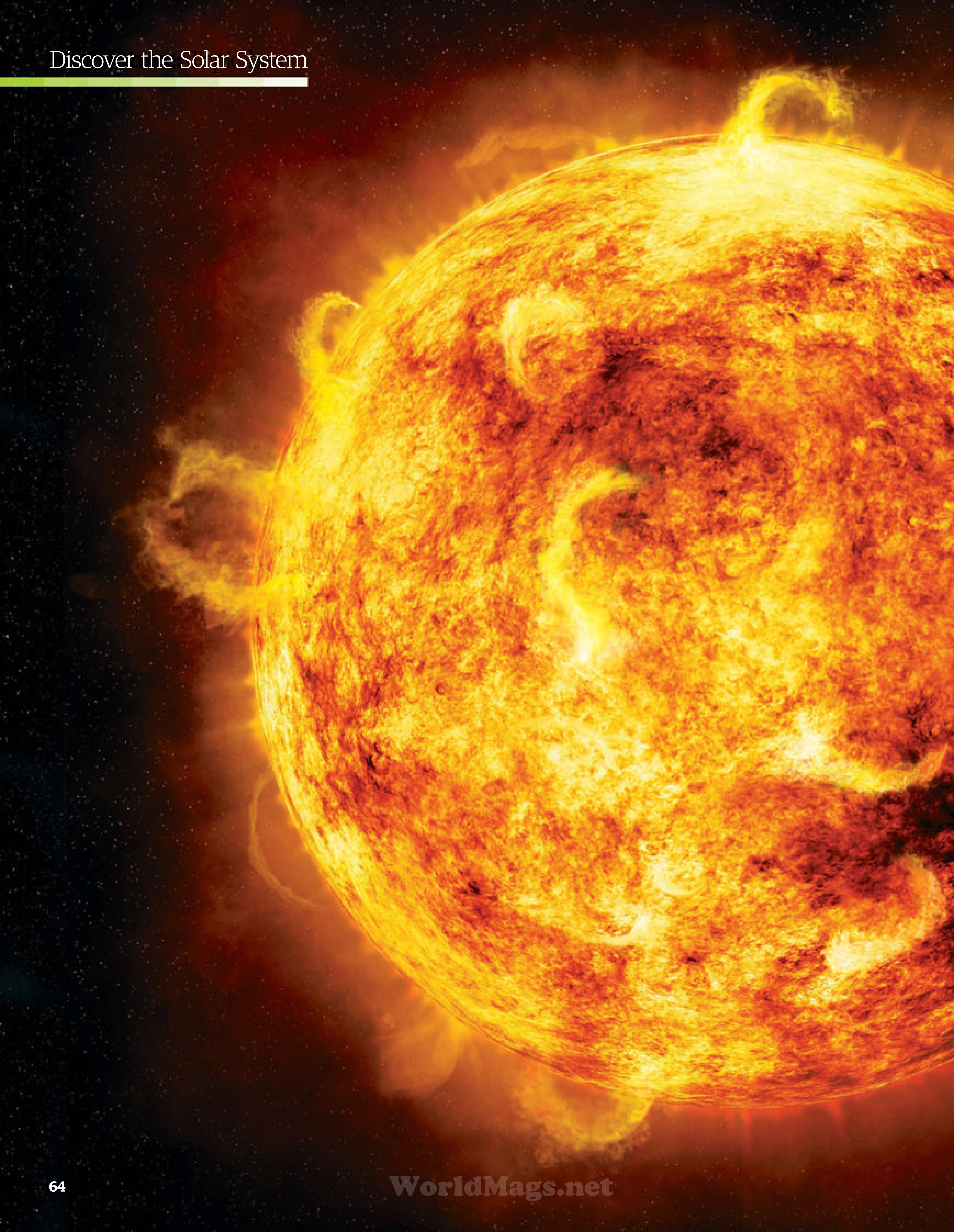
© NASA

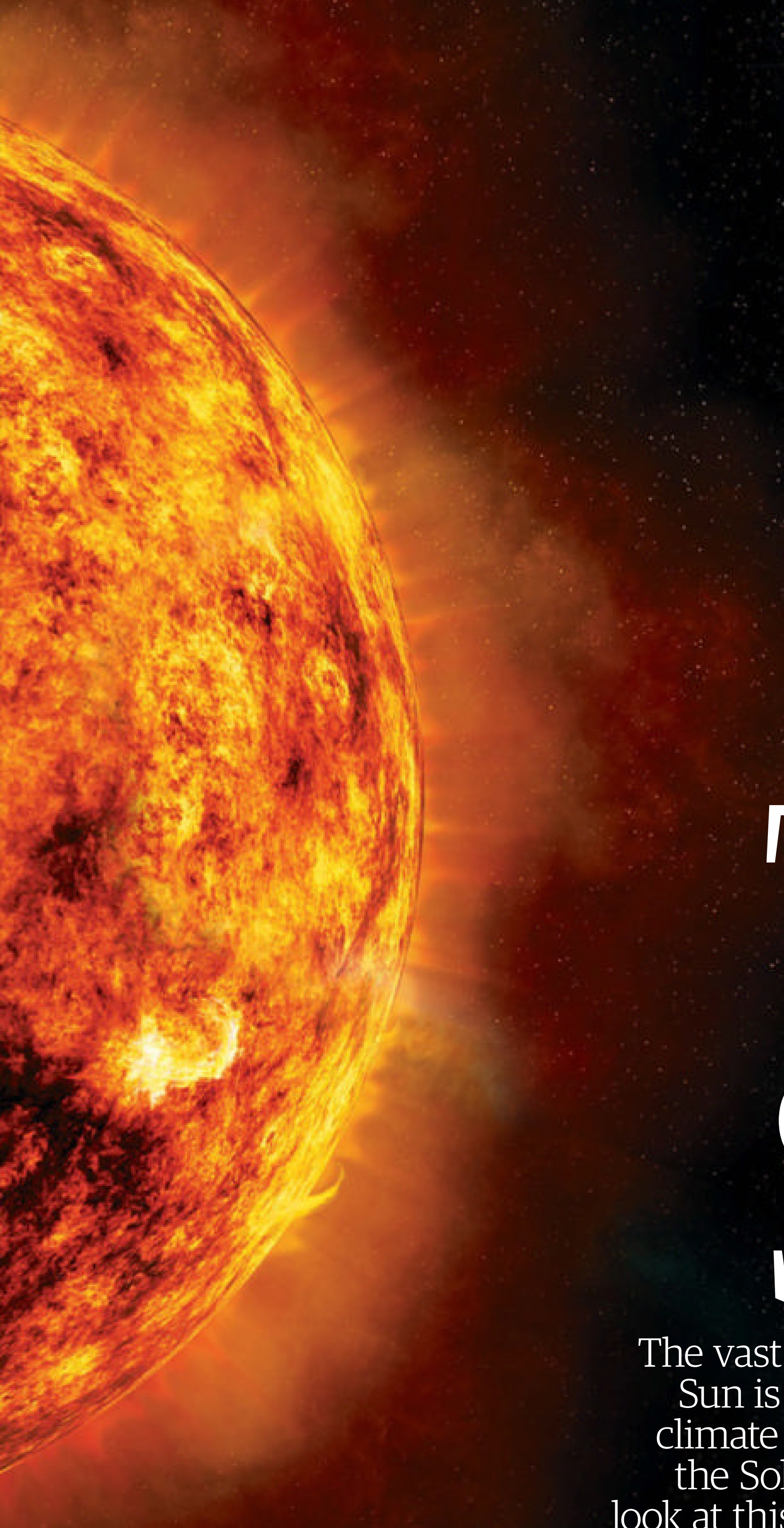
Discover the Solar System

Exploring the wonders of our Solar System



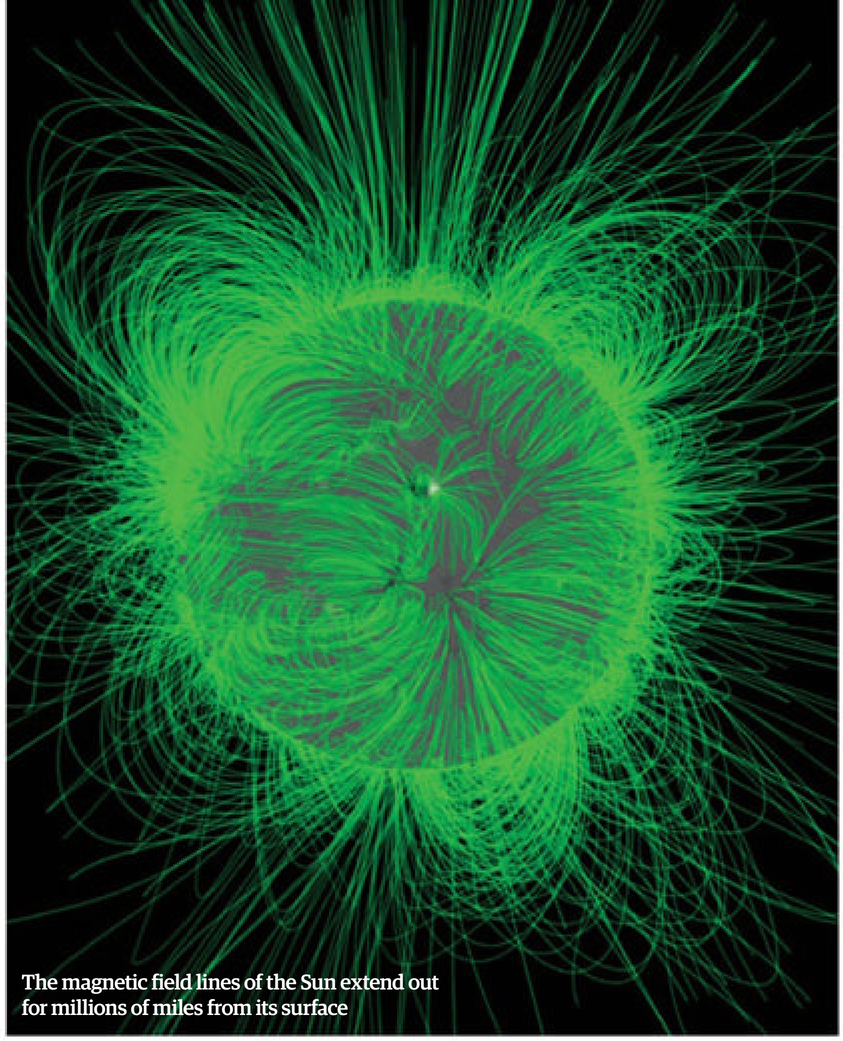
©NASA, Alamy





All About… THE SUN

The vast nuclear furnace that we know as the Sun is responsible for dictating the seasons, climate and characteristics of every planet in the Solar System. Here, we take an in-depth look at this source of power that has astounded humanity since the dawn of existence



The magnetic field lines of the Sun extend out for millions of miles from its surface

At about 150 million kilometres (93 million miles) from Earth lies a giant incandescent ball of gas weighing in at almost 2,000 trillion trillion kilograms and emitting power equivalent to 1 million times the annual power consumption of the United States in a single second. Since the dawn of Earth 4.6 billion years ago it has been the one ever-present object in the sky, basking our world and those around us in energy and light and providing the means through which environments, and ultimately life, can flourish. We see it every day and rely on its energy to keep our planet ticking, but what exactly is this giant nuclear reactor at the centre of the Solar System that we call the Sun?

Over 5 billion years ago a vast cloud of dust and gas was located where our Solar System is now. Inside this nebula something huge was happening; gravity was pulling together the debris, likely the remnants of another star going supernova, into one central mass. As the various metals and elements were brought together they began to fuse into an object at the heart of this nebula. This dense clump of matter, called a protostar, grew and grew in size until it reached a critical temperature due to friction, about 1 million degrees Celsius (1.8 million degrees Fahrenheit). At this point nuclear fusion kicked in and our Sun was born.

At the heart of the Sun, hydrogen atoms fused together to produce helium, releasing photons of light in the process that extended throughout the Solar System. Eventually the hydrogen and helium atoms began to fuse and form heavier elements such as carbon and oxygen, which in turn formed key components of the Solar System, including humans. To us, it's the most important object in the sky. An observer watching from afar, however, would see no discerning qualities of our star that would make it stand out from any of the other hundreds of billions of stars in the Milky Way. In the grand scheme of things it's a fairly typical star that pales in comparison to the size of others. For instance Sirius, the brightest star in the night sky, is twice as massive as the Sun and 25 times more luminous while Arcturus, the fourth brightest object in the night sky is almost 26 times the size of our closest star.

The Sun is located at a mean distance of 150 million kilometres (93 million miles) from Earth, a distance known as one astronomical unit (1 AU). This giant nuclear furnace is composed mostly of ionised gas and drives the seasons, ocean currents, weather and climate on Earth. Over a million Earths could fit inside the Sun, which is itself held together by gravitational attraction, resulting in immense pressure and temperature at its core. In fact, the core reaches a temperature of about 15 million degrees Celsius (27 million degrees Fahrenheit), hot enough for thermonuclear fusion to take place. The intense physical process taking place in the Sun produces heat and light that radiates throughout the Solar System. It's not a quick process, though; it takes more than 170,000 years for energy from the core to radiate outwards towards the outer layers of the Sun.

Our Sun is classified as a yellow dwarf star and these stars range in mass from about 80 per cent to 100 per cent the mass of the Sun, meaning our star is at the upper end of this group. There are also three further groups into which stars are classified: Population I, II and III. Our Sun is a Population I star, which denotes that it contains more heavy elements compared to other stars (although still accounting for no more than approximately 0.1 per cent of its total mass). Population III stars are those that formed at the start of the universe, possibly just a few hundred million years after the Big Bang, and they are made from pure hydrogen and helium. Although hypothesised, no such star has ever been found, as the majority of them exploded as supernovae in the early universe and led to the formation of Population I and II stars, the latter of which are older, less luminous and colder than the former.

By now you're probably thinking our Sun is insignificant, but that's anything but the case. Being our closest star, and the only one we can study with orbiting telescopes, it acts as one of the greatest laboratories available to mankind. Understanding the Sun allows us to apply our findings to research here on Earth, such as nuclear reactors, and our observations of distant stars. Over the next few pages we'll delve into the reasons why studying the Sun is so important and explore some of the amazing physics going on inside and outside this vast nuclear furnace.

"The core reaches a temperature of about 15 million degrees Celsius, hot enough for thermonuclear fusion to take place"

Spicules
These supersonic jets of hot plasma form in the Sun's interior and rise to a height of around 5,000km (3,000 miles) above the Sun's photosphere

Coronal mass ejections
A coronal mass ejection (CME) is a burst of plasma and magnetic fields, known as stellar wind, being thrown into space from the Sun's corona

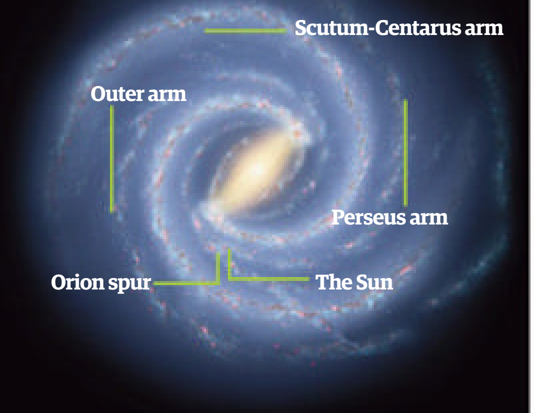
Faculae
Produced by concentrations of magnetic field lines, these bright spots appear on the Sun's chromosphere in regions where a sunspot will form

Granulation
The Sun often appears granulated in images because of convection currents in its photosphere and chromosphere

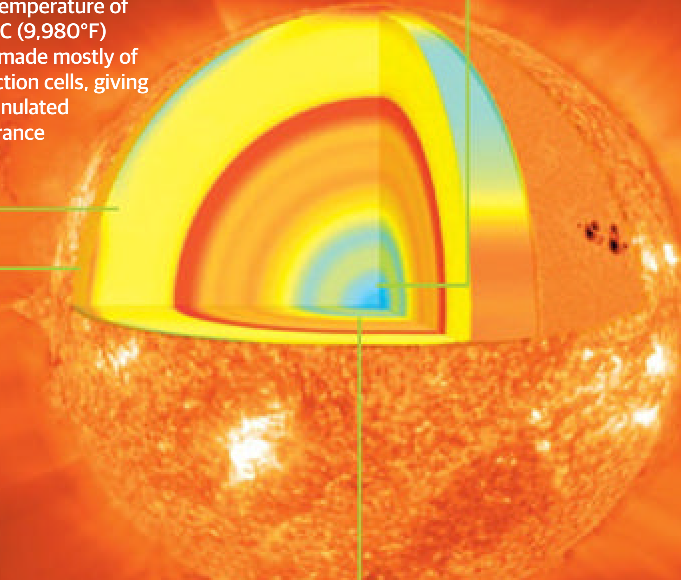
Prominences
These large loops of energy extend outwards from the Sun's corona. They can range over 700,000km (430,000 miles), approximately the radius of the Sun

Sunspot
These dark spots on the surface of the Sun are caused by intense magnetic fields and are usually accompanied by a solar flare or CME

Our Solar System is located in the outer reaches of the Milky Way galaxy, which has roughly 200 billion stars



Layers of the Sun



Photosphere
The visible surface of the Sun, the photosphere, has a temperature of 5,530°C (9,980°F) and is made mostly of convection cells, giving it a granulated appearance

Inner core
Most of the Sun's fusion power is generated in the core, which extends outwards from the centre to about a quarter of the Sun's radius

Corona
The outer 'atmosphere' of the Sun. It is made of plasma, extends millions of kilometres outwards and has a higher temperature than the inner photosphere

Chromosphere
This thin layer about 2,000km (1,240 miles) thick sits just above the photosphere and is the area where solar flares and sunspots are visible

Radiative zone
This area is full of electromagnetic radiation from the core that bounces around as photon waves. It makes up about 45 per cent of the Sun

Solar storms

Like the Earth, the Sun has an atmosphere, but the two are very different. The Sun's can be incredibly volatile with powerful magnetic activity that causes phenomena referred to as solar storms here on Earth

Solar storms are violent outbursts of activity on the Sun that interfere with the Earth's magnetic field and inundate our planet with particles. They are the result of outpourings of energy from the Sun, either in the form of a Coronal Mass Ejection (CME) or a solar flare. The former is a release of a large amount of material, mostly plasma, from the Sun while the latter is a sudden release of electromagnetic radiation commonly associated with a sunspot. While no direct connection has been found between CMEs and solar flares, both are responsible for causing solar storms on Earth. The reason why these two events occur is due to the Sun's atmosphere and its turbulent interior, with all of its components playing a part in bathing our planet in bursts of energy.

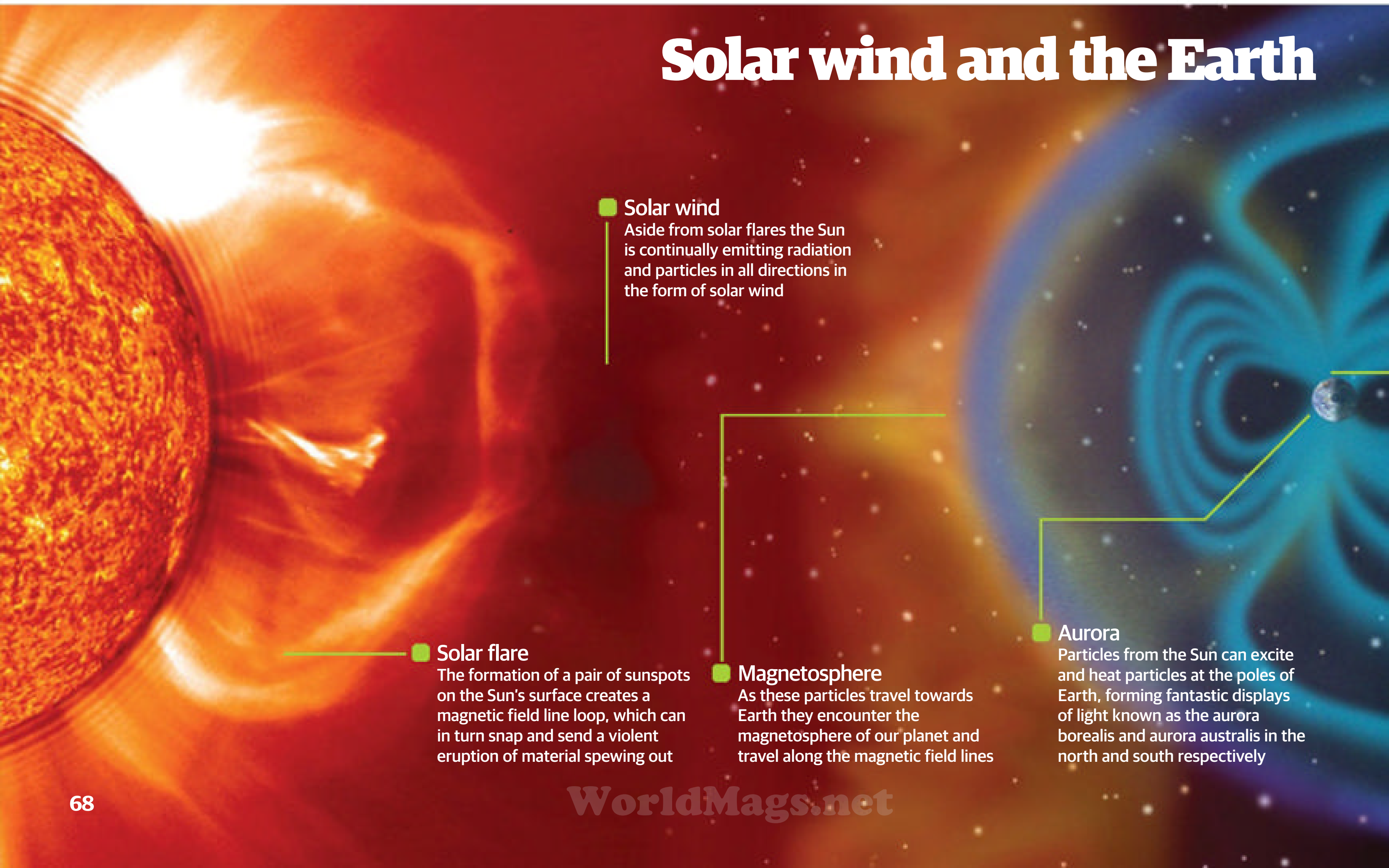
The lowest part of the atmosphere, the part directly above the Sun's radiative zone, is the photosphere. This is the visible part of the Sun that we can see, it is 300-400 kilometres (180-240 miles) thick and has a temperature of about 5,530 degrees Celsius (9,980 degrees Fahrenheit). This produces a white glow although from Earth this usually appears yellow or orange due to our own atmosphere.

As you travel through the photosphere away from the Sun's core the temperature begins to drop and the gases become cooler, in turn emitting less light. This makes the photosphere appear darker at its outer edges and gives the Sun an apparently clearly defined outer boundary, although this is certainly not the case as the atmosphere extends outwards much further.

Once you pass through the photosphere you enter the chromosphere, which is about 2,000 kilometres (1,240 miles) thick. The temperature rises to about 9,730 degrees Celsius (17,540 degrees Fahrenheit), surpassing that of the photosphere. The reason for this is that the convection currents in the underlying photosphere heat the chromosphere above, producing shock waves that heat the surrounding gas and send it flying out of the chromosphere as tiny spikes of supersonic plasma known as spicules.

The final layer of the Sun's atmosphere is the corona. This huge

Solar wind and the Earth



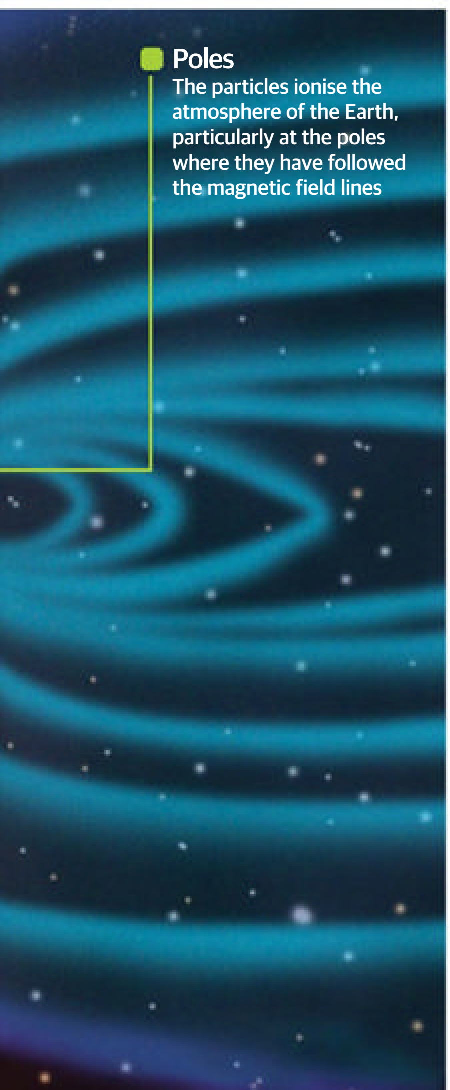
Particles ejected from the Sun can cause fantastic light displays at Earth's poles, known as the aurora borealis (or Northern Lights) and the aurora australis (or Southern Lights)

> "Once you pass through the photosphere you enter the chromosphere, which is about 2,000km thick"

expanse of material can stretch as far as several million miles outwards from the surface. Oddly, the temperature of the corona averages 2 million degrees Celsius (3.6 million degrees Fahrenheit), far hotter than that of the photosphere and chromosphere. The reason for this is unknown; as far as we are aware, atoms tend to move from high to low temperatures and not vice versa, so the process of material moving out of the Sun beyond the photosphere is not understood.

On the photosphere, dark and cool regions known as sunspots appear in pairs as a result of intense magnetic fields. The magnetic fields, caused by gases moving in the Sun's interior, leave one sunspot and enter another. Sunspot activity rises and falls on an 11-year cycle, as discussed in the next section. Sometimes clouds of gases from the chromosphere will follow these magnetic field lines in and out of a pair of sunspots, forming an arch of gas known as a solar prominence. A prominence can last up to three months and may extend up to 50,000 kilometres (30,000 miles) above the surface of the Sun. Once they reach their maximum height they break and erupt, in turn sending massive amounts of material racing outwards through the corona, an event which is known as a coronal mass ejection (CME).

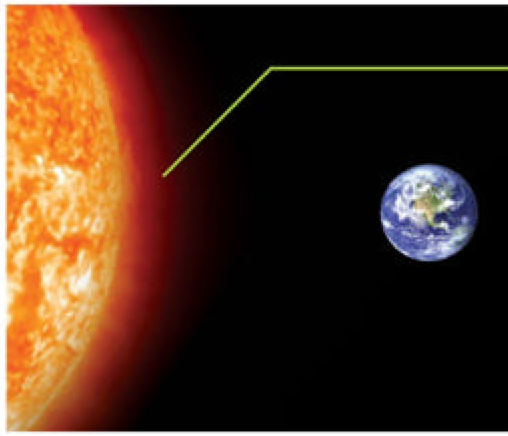
When the sun's magnetic field is concentrated in sunspot areas, the resultant magnetic field lines can extend and snap, causing a violent explosion on the surface of the Sun called a solar flare. At the moment of eruption vast amounts of radiation are emitted into space, which we call a solar storm when it reaches Earth. The particles within a solar storm often interact with particles in the atmosphere of planets in the Solar System, causing fantastic displays of light at their poles as the gases in the planet's atmosphere are heated by the particles. On Earth we know these as the aurora borealis in the Northern Hemisphere and the aurora australis in the Southern Hemisphere.



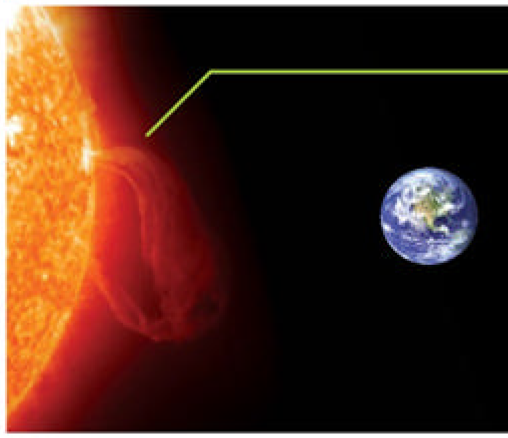
Poles
The particles ionise the atmosphere of the Earth, particularly at the poles where they have followed the magnetic field lines

How solar storms work

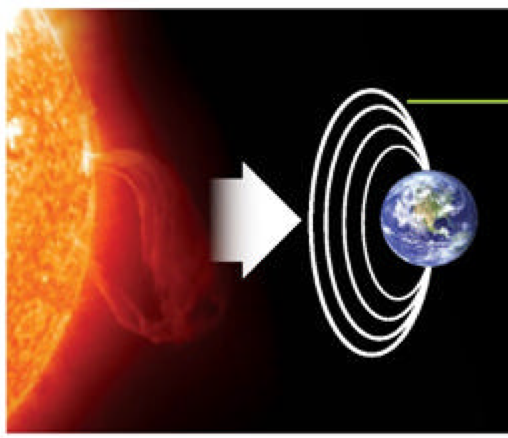
Vast amounts of radiation heading for Earth



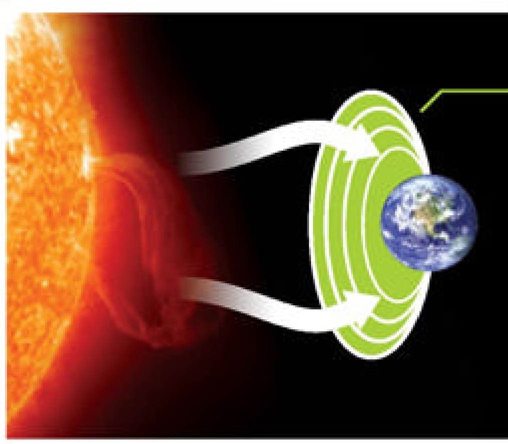
Explosion
A solar flare can release up to 6x10^25 joules of energy as it explodes from the surface of the Sun. The giant clouds of radiation and particles can take up to two days to travel to the Earth



Cycle
Solar flares peak in 11-year-long activity cycles. The cause of these cycles is unknown. In periods of inactivity there can be less than one flare a week but when the Sun is at its busiest there can be several every day



Intensity
Solar wind typically travels at 1.6 million kph (one million mph), but the explosive event that emits a solar flare can send it hurtling towards the Earth up to four times faster



Magnetosphere
The magnetic field surrounding the Earth acts as a barrier from the Sun's activity, but some of the particles travel along the magnetic field lines and excite particles in our atmosphere, in turn causing auroras to form at the poles

The solar cycle

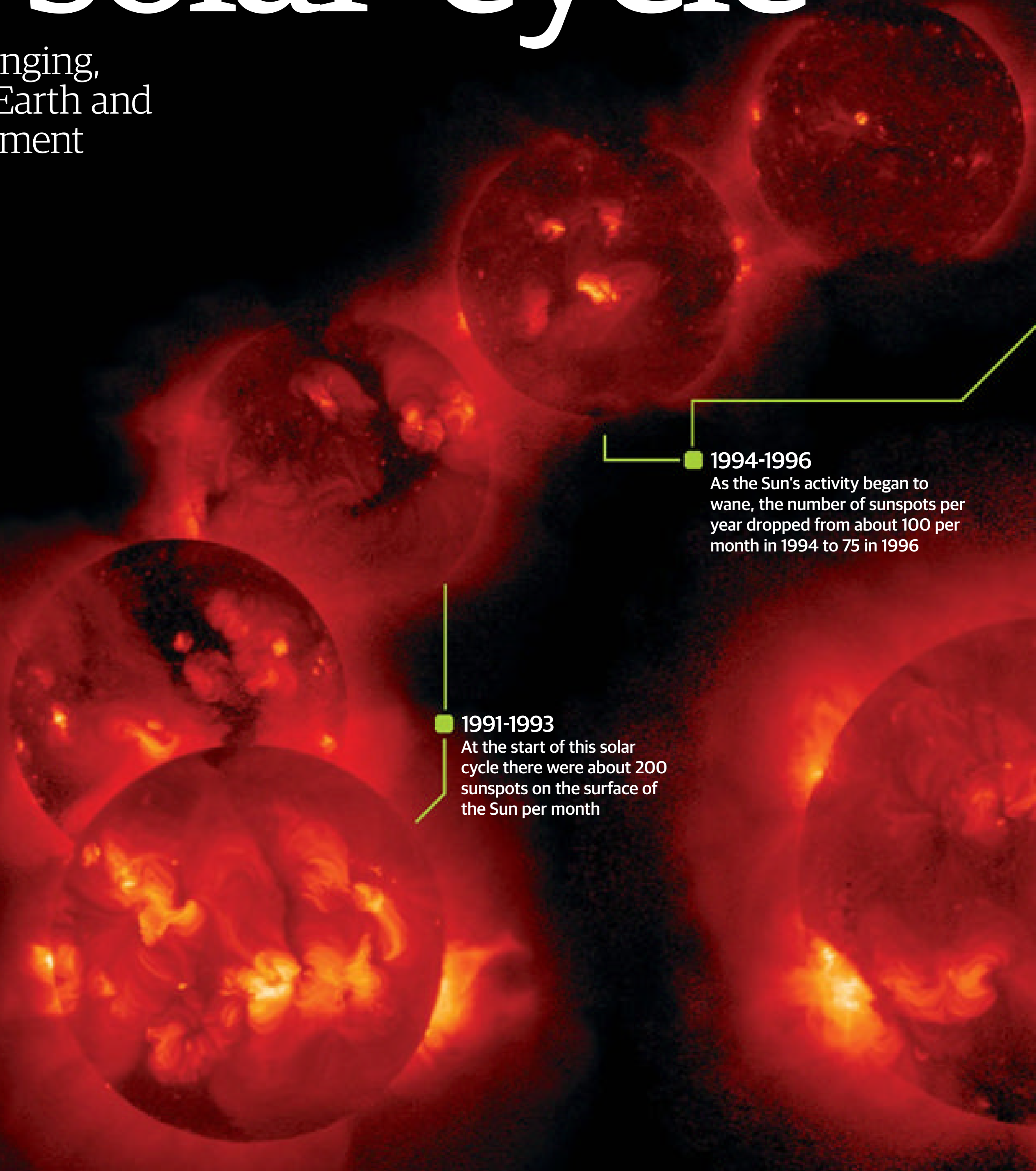
Our Sun is ever-changing, affecting all life on Earth and our natural environment

Our Sun may be a great distance away but its fluctuations and perturbations are still felt here on Earth.

Every 11 years the Sun moves from a period of low activity, known as a solar minimum, to a period of high activity, known as a solar maximum, and back again. When it is at its most active the Sun is even more violent than usual, with a greater number of sunspots appearing on its surface and therefore more solar flares emitted into space. During its minimum point it is still a raging inferno firing material into space but, by comparison, it is much quieter and sunspots, and therefore solar storms, are rare.

Cycles are observed by monitoring the frequency and position of sunspots on the Sun. When the Sun reaches the end of its cycle, new sunspots will appear near the equator. The beginning of the next cycle will see sunspots appear at higher latitudes on the surface of the Sun.

Solar cycles have been observed for centuries, but a standardised method of counting them was not devised until 1848 when Johann Rudolf Wolf started counting sunspots on the solar disk and calculated the Wolf number, which is still used today to keep track of the solar cycle. Cycles vary in their intensity. From 1645 to 1715 there were few sunspots present on the Sun, a period known as the Maunder Minimum. The number of sunspots has been relatively more uniform this century, with cycles having an average period of 10.5 years. The Sun also has a 22-year magnetic cycle where, every 22 years, its magnetic field flips from pole to pole. This doesn't have a noticeable effect on the Solar System, but indicates when the solar maximum of the current cycle has been reached. However, the reason for these cycles remains a mystery. No one yet has any clear understanding as to why the Sun has periods of varying activity.



10 years of the Sun

These X-ray images were taken by Japan's Yohkoh Solar Observatory and show the changes in the Sun's corona over a ten-year cycle between 30 August 1991 and 6 September 2001

"Solar cycles have been observed for centuries, but a method of counting them was not devised until 1848"

The Scientist's view

How we understand solar cycles

"Sun-Earth interaction is complex, and we haven't yet discovered all the consequences of solar cycle variation on Earth's environment. We saw a large amount of geomagnetic activity driven by recurring fast solar wind streams during the recent solar minimum. A surprising departure from the consistently low activity we'd come to expect from previous minima, especially considering the record low level of sunspots. These new observations deepen our understanding of how solar quiet intervals affect the Earth and how and why this might change from cycle to cycle."

Sarah Gibson, UCAR, @AtmosNews

The Sun by numbers

Fantastic figures and surprising statistics about our nearest star

99.86%

The Sun's percentage of mass of the entire Solar System

Less than 5% of stars in the Milky Way are brighter or larger than the Sun

1 million Earths Would fit inside the Sun

164 watts *Is the amount of energy every square metre of the Earth's surface receives. That's the equivalent of a 150-watt table lamp on every square metre of the Earth's surface*

498 seconds

How long it takes light to travel from the Sun

100 BILLION

TONS of dynamite would have to be detonated every second to match the energy produced by the Sun

The SOHO mission

The Solar and Heliospheric Observatory was launched in December 1995 and is helping us explore the Sun

Interview

SOHO project scientist Bernhard Fleck tells us why studying the Sun is important to Earth

1. Understand life
"The Sun provides the energy for all life on Earth. It seems quite natural that we are curious to know more about the star from which we live."

2. Understand climate
"Solar radiation is the dominant energy input into the terrestrial ecosystem. The Sun provides a natural influence on the Earth's atmosphere and climate. To understand mankind's roles in climate change, the Sun's impact must be understood."

3. Predict space weather
"Our Sun is very dynamic and produces the largest eruptions in the Solar System. These solar storms can reach our planet and adversely affect technologies such as satellites and power grids. Space weather becomes increasingly important as our society depends more on modern technologies."

4. Learn about stars
"If we want to understand the universe, we have to understand the evolution of galaxies. To understand galaxies, we need to understand the evolution of stars that make up the galaxies. If we want to understand stars, we better understand the Sun, the only star we can resolve in great detail."

5. Stellar physics lab
"The Sun lets us study basic physical plasma processes under conditions that can't be reproduced on Earth."

The Solar and Heliospheric Observatory, also known as SOHO, was launched on 2 December 1995. It was built in Europe by prime contractor Matra Marconi Space, which is now EADS Astrium. The spacecraft is operated jointly by the ESA and NASA. It studies the Sun in depth, all the way from its deep core to its outer corona and its solar wind.

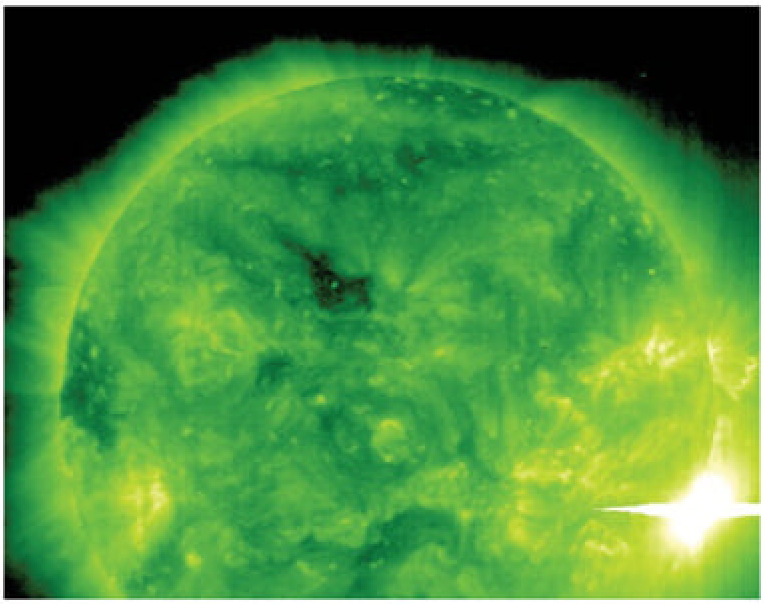
SOHO is made of two modules, the Service Module and the Payload Module. The former provides SOHO with power, while the latter houses all of the instruments on the spacecraft. Overall, there are 12 instruments on board SOHO, nine of which are run by Europe as well as three from the United States.

SOHO is located near to Lagrangian point 1, which is a point between the Earth and the Sun about 1.5 million kilometres (930,000 miles) from our planet. It is the point where the gravitational attraction of the Sun and the Earth cancel out, so a telescope such as SOHO can remain in a stable orbit to observe the Sun. SOHO is one of the only telescopes currently capable of detecting incoming solar flares that could be potentially hazardous to satellites and other electronics on Earth.

Of the 12 instruments on board SOHO one of the most interesting is the Large Angle and Spectrometric Coronagraph (LASCO), which studies the Sun's corona by creating an artificial solar eclipse. The LASCO instrument has been largely responsible for inadvertently discovering many comets near the Sun, with over 1,800 found to date.

SOHO has three primary objectives that it has been carrying out since its launch. One of these was to investigate the outer regions of the Sun, specifically the corona.

At the moment it is still unknown why the corona is hotter than the photosphere and chromosphere of the Sun, so it is hoped that SOHO might help to provide the answer in the future. SOHO has also been used to observe the solar wind, and also to study the interior structure of the Sun through a process known as helioseismology.



On the scale of solar flares, X-class storms are most powerful. SOHO took this image on November 2003 showing the most powerful ever recorded, which reached X28

Take a tour of SOHO

SOHO is made up of two modules. The Service Module forms the lower portion, while the Payload Module sits above

Payload Module
This sits on top of the Service Module and houses all 12 of the instruments on board the spacecraft

Service Module
The Service Module provides power, telecommunications, thermal control and direction to the spacecraft

Malfunction
In 1998 SOHO suffered a major malfunction that almost rendered it unusable. However, some smart thinking enabled scientists to regain control of the telescope, although it now operates without the help of its gyroscopes, the only three-axis stabilised spacecraft to do so

Mission Profile

Solar and Heliospheric Observatory (SOHO)

Mission dates: 02/12/95-12/12/14

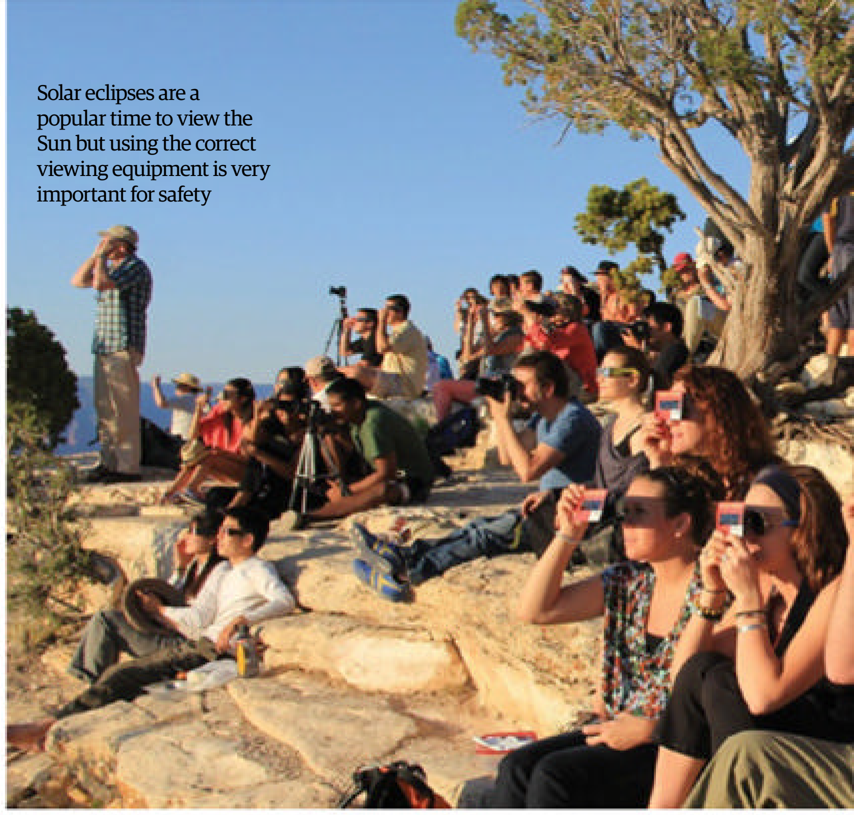
Details: SOHO is a joint project between the ESA and NASA. It was designed to study the origin of the solar wind, the outer atmosphere of the Sun and its internal structure. SOHO has found over 1,800 comets to date and discovered that quakes on the Sun's surface are caused by solar flares. It has also made the most detailed map of features on the solar surface.

The SOHO spacecraft has survived 17 years in space, 15 more than its initial mission length

"SOHO is located near to Lagrangian 1, which is a point between the Earth and the Sun about 1.5 million km (930,000 miles) from our planet"

Observing the Sun

Humanity has been fascinated by the Sun for thousands of years and even primitive records still prove useful. Discover more about the past, present and future of studying the Sun



Solar eclipses are a popular time to view the Sun but using the correct viewing equipment is very important for safety

Observations of the Sun have been used for both scientific and religious observations for millennia. Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC, while scientists such as Galileo studied the Sun through telescopes to discern some of its characteristics.

At the Chankillo archaeological site in Peru can be found the oldest solar observatory in the Americas, a group of 2,300-year-old structures used to track the motion of the Sun known as the Thirteen Towers. These towers provide a rudimentary solar calendar through which the Sun can be traced.

The towers, each between 75 and 125 square metres (807 and 1,345 square feet) in size, run from north to west along a ridge along a low hill. From an observation point to the west of the ridge the Sun can be seen to rise and set at different points along the ridge, which allowed ancient civilisations to track the number of days it takes the Sun to move from tower to tower.

Much later, in 1612, the renowned Italian astronomer Galileo Galilei (1564-1642) used his telescope to make one of the first observations of sunspots on the surface of the Sun. In 1749 daily observations began at the Zurich Observatory and, since 1849, continuous observations have been made to count the number of sunspots present on the Sun's surface at any one time.

Fast forward to today and, aside from SOHO, one of the primary telescopes used to observe the sun is the Japanese Hinode spacecraft. Hinode is a telescope in sun-synchronous Earth orbit, which allows for nearly continuous observation of the Sun. It was launched on 22 September 2006 and was initially planned as a three-mission study of the magnetic fields of the Sun, but its mission has since been extended as it continues to operate nominally.

Another important Sun-observing telescope is the Solar Dynamics Observatory (SDO), launched by NASA in 2010. The goal of the SDO is to study the influence of the Sun near Earth, predominantly how the Sun's magnetic field is responsible for the solar wind once it is released into the heliosphere. It should help scientists further understand the Sun's influence on the Solar System.

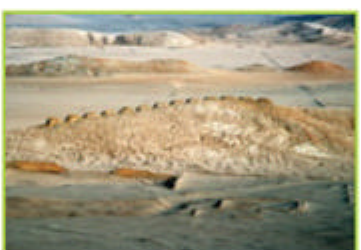
In the future, NASA's Solar Probe Plus will be the closest spacecraft to the Sun, approaching to within just 8.5 solar radii (5.9 million km, 3.67 million miles, 0.04 AU) after its launch in 2018. It will probe the outer corona of the Sun in unprecedented detail, while also becoming the fastest spacecraft of all time in the process at up to 200km per second (120 miles per second).

Apart from million dollar telescopes, many amateur astronomers around the globe today observe the Sun either for entertainment or educational benefit. Using specially designed glasses people can look at the Sun from Earth, although caution must be taken to limit time spent looking at the Sun and it should never be looked at with the naked eye. Other methods of solar observation include using a telescope to produce a trace of the Sun, a method similar to that used by Aristotle and his camera obscura in the 4th Century BC. Again, precautions must be taken here, as under no circumstances should the Sun be directly observed through a telescope.

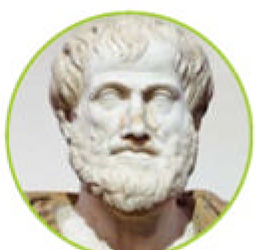
Whatever the method, and whatever the mission, observations of the Sun have been a long tradition and will continue to be so for the foreseeable future. Astronomical events such as planetary transits and solar eclipses provide amateur astronomers with opportunities to see extraordinary solar phenomena, while agencies throughout the world will continue to study the Sun and learn more about how the fantastic star works.

> "Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC"

The history of observing the Sun



400BC
The world's oldest solar observatory, the Thirteen Towers of Chankillo, is built in Peru to track the motion of the Sun.



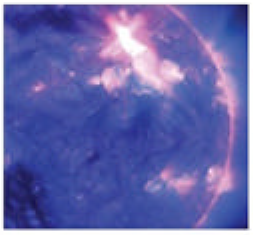
350BC
Aristotle uses a camera obscura to project an image of the Sun and observe a partial eclipse.

1612
Galileo Galilei uses his telescope to make one of the first observations of sunspots on the surface of the Sun.

A telescope with a digital screen can be used to safely observe the Sun

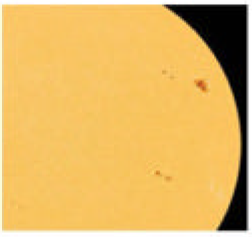
Different ways to observe the Sun

On Earth we perceive the Sun to be a yellow ball of gas in the sky but, like anything as hot as the Sun, it is actually closer to being white hot when viewed from space. There are several telescopes currently observing the Sun but the large majority of our images come from the STEREO telescope and the SOHO observatory, both in orbit around the Sun. By viewing the Sun in different wavelengths we can study its different characteristics and see some of its main features in a different light.



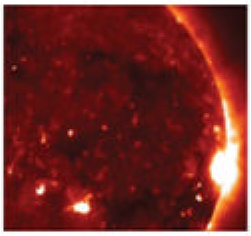
Ultraviolet

Images of the Sun in ultraviolet light are between wavelengths of about 19.5 and 30.4 nanometres. Such an image of the Sun is at the lower end of this scale, and allows us to see where the lower part of the corona and upper part of the chromosphere combine. The light in this image comes from active regions in the Sun's chromosphere.



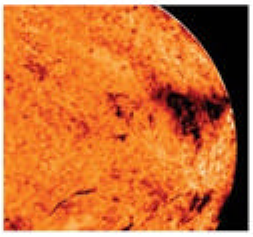
Visible

Visible light images commonly refer to those viewing the Sun in white light, which shows the true colour of the white-hot Sun. In visible light images we can see the Sun's photosphere, which is about 6,000 degrees Celsius (10,832 degree Fahrenheit) and therefore appears white-hot. Here, we can see dark spots on the surface of the Sun, known as sunspots.



X-ray

Light with a wavelength shorter than ten nanometres (ten billionths of a metre) is known as X-ray light. X-rays are emitted from the Sun's corona, the hottest visible layer of the Sun's atmosphere. The visible areas of brightness are places where more X-rays are being emitted, around areas of increased activity on the Sun's surface.

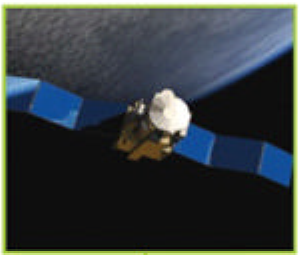


Infrared

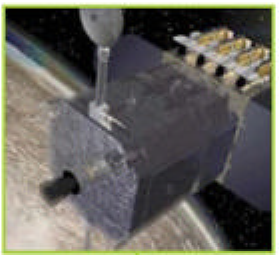
Infrared light is responsible for more than half of the Sun's power output, typically around wavelengths of 1,080 nanometres. Infrared images show features of the Sun's chromosphere and corona. The dark features on the image are areas where the gas is more dense, absorbing more infrared light than in other areas.

1749
Daily observations of the Sun begin at the Zurich Observatory in Switzerland.

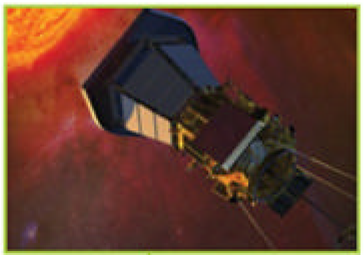
1849
New observatories around the world allow continuous observations of sunspots to be made.



2006
The Japanese telescope Hinode is launched to study the magnetic fields and atmosphere of the Sun.



2010
NASA launches the Solar Dynamics Observatory, its primary goal being to study the influence of the Sun near Earth.



2018
NASA's new Sun-observing telescope Solar Probe Plus will launch and become the closest spacecraft to the Sun.

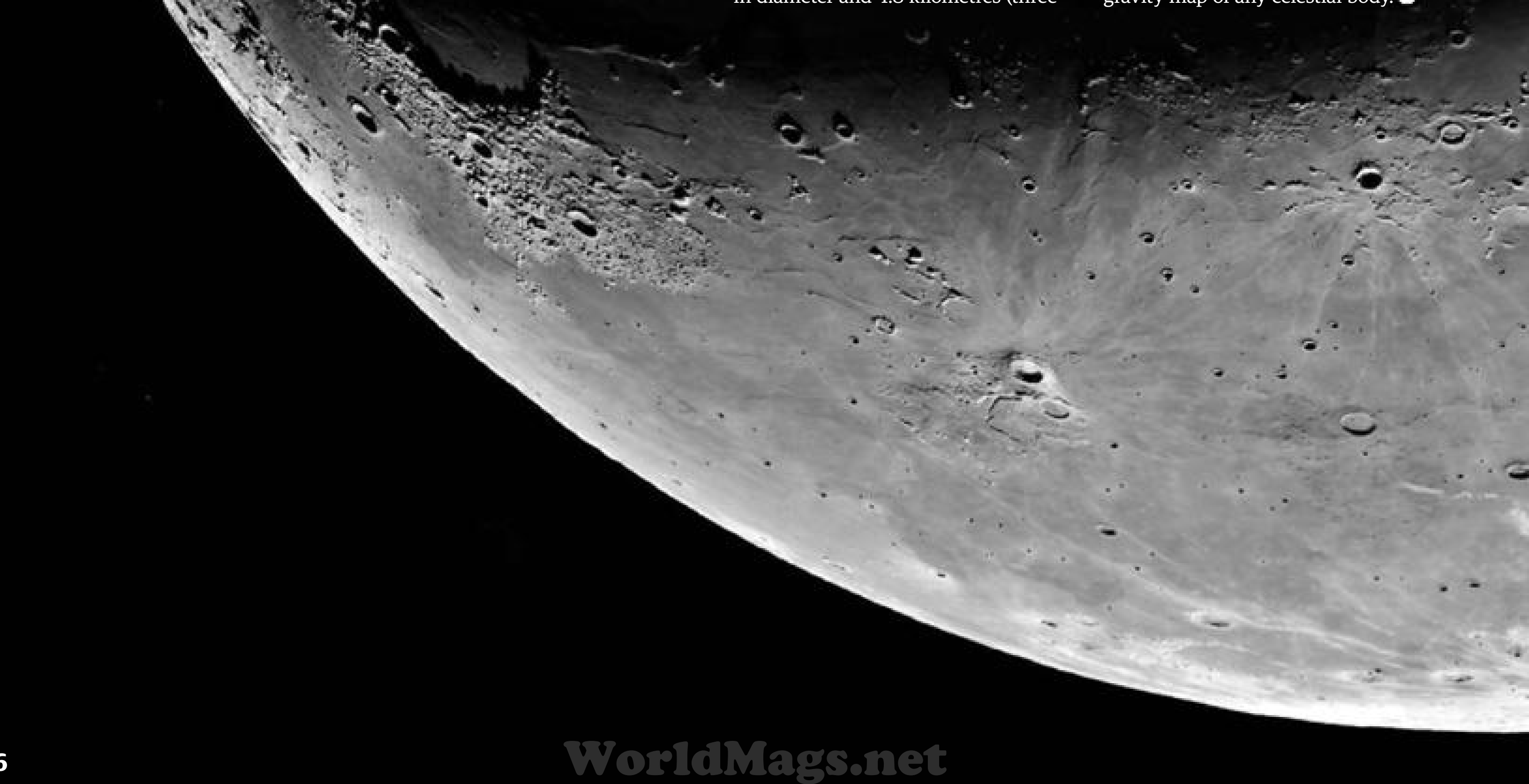
The Moon

The most visible celestial object from Earth has been the source of human fascination for millennia, yet we're still discovering more about it all the time

Orbiting at a distance of anywhere between 362,570 kilometres and 405,410 kilometres (225,000 to 252,000 miles) and moving away from the Earth at almost four centimetres (1.57 inches) per year, all 74 billion trillion kilograms (160 billion trillion pounds) of blasted grey rock that is the Moon never fails to make for fascinating viewing. Its topography is a pattern of 'maria' – impact basins once filled with lava – and giant craters that are clearly visible from Earth.

Most notable of these is Tycho on the near side of the Moon. Despite being around 86 kilometres (53 miles) in diameter and 4.8 kilometres (three miles) deep, it's not the largest of the Moon's impact features: that accolade goes to the South Pole-Aitken basin on the far side, which is 2,500 kilometres (1,550 miles) in diameter, 13 kilometres (eight miles) deep and one of the biggest craters in the Solar System. But with its distinctive ray system fanning out for hundreds of kilometres across the surface in all directions, Tycho is the Moon's most recognisable feature.

We're still learning about the Moon, the most recent major mission being the Gravity Recovery and Interior Laboratory (GRAIL) mission that generated the highest resolution gravity map of any celestial body.



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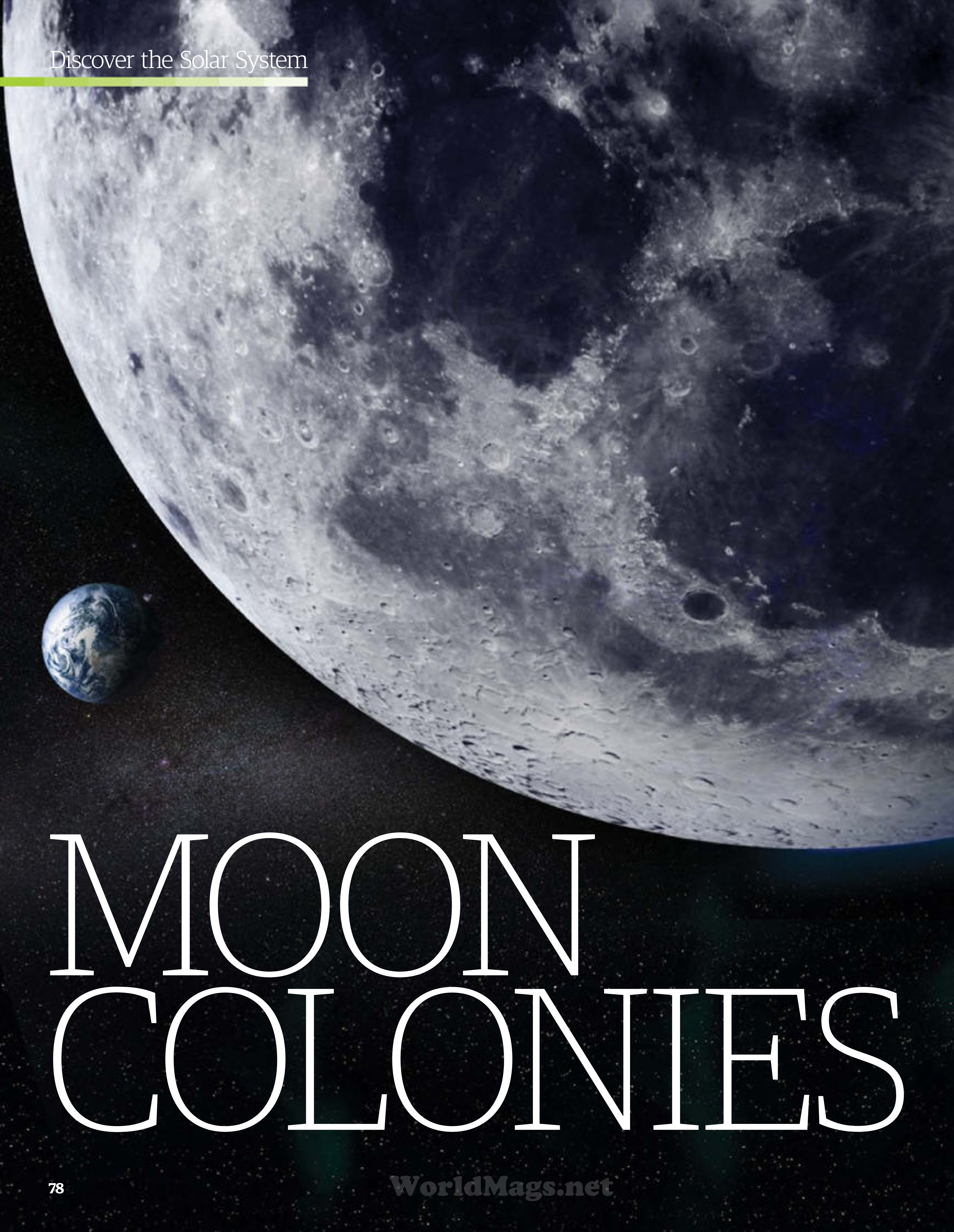


MOON COLONIES

As the 40th anniversary of the last manned Moon mission passed in 2012, we investigated the progress being made towards establishing a permanent lunar base on the surface of our satellite

"America's challenge of today has forged man's destiny of tomorrow," said Apollo 17 astronaut Gene Cernan as he stepped back into the Lunar Module with fellow astronaut Jack Schmitt on 14 December 1972. The Apollo missions were expected to kickstart an age of human space exploration including lunar colonies, manned Mars missions and possibly ventures beyond. But four decades later, and the pipe dreams of 20th Century visionaries seem further away than that fateful first step in 1969.

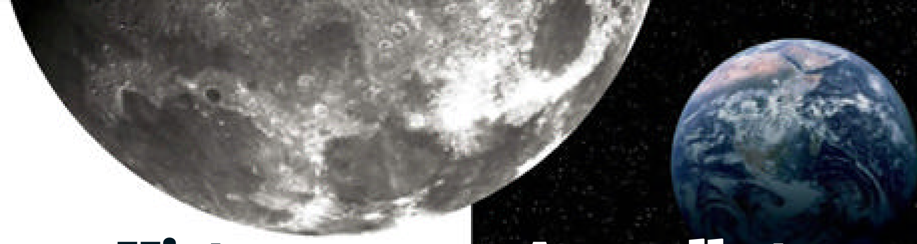
It's no exaggeration to say that, in the year 2012, many had predicted space to be teeming with human life. The fact that it's not, save for a handful of astronauts aboard an orbiting space station, is a disappointment to many a space enthusiast. But is it really all doom and gloom? Are we truly destined to remain constrained to our Blue Planet, left to observe the Moon from afar rather than setting foot, and living, where only a dozen men have done so before?

"If something can be done, it ultimately will be done," says Dr Paul Spudis, talking to us about the possibility of a future Moon settlement. "If at some point it makes sense for the Moon to be permanently inhabited, then it will happen."

Dr Spudis is somewhat of an expert when it comes to lunar exploration. He is currently a senior staff scientist at the Lunar and Planetary Institute in Houston, Texas, and has worked on both the Indian Chandrayaan Moon programme and NASA's Lunar Reconnaissance Orbiter. He also served on a White House panel to analyse a return to the Moon and the establishment of a lunar base.

From the outside looking in a possible Moon colony might seem improbable, if not impossible, but it's an idea that has been suggested by scientists since the dawn of the space age, including Dr Spudis himself.

"I advocate a return to the Moon to use it for the creation of a new space-faring capability," says Dr Spudis. "That essentially means that we hope to extract the material and energy resources of the Moon to build a permanent, space-faring capability. In practical terms that means, initially, the extraction of water from the deposits near the lunar poles and its use for a variety of purposes, mostly rocket propellant but also human life support and power storage. Eventually, we can build structures from lunar materials, but water is the easiest and most useful substance to get at first."



The reference of water on the Moon is an important one, and is one of the primary reasons that lunar exploration has become such an intriguing talking point once again. The discovery of water on the lunar surface was formally announced by NASA on 24 September 2009. Found by the Chandrayaan-1 orbiter and impact probe, it was a huge announcement with far-reaching ramifications.

As Dr Spudis mentions, water is a vital ingredient for any form of manned space exploration. It's essential for life, and its constituents (hydrogen and oxygen) also happen to be the primary components of rocket fuel. Previous visions of a lunar base envisioned a colony constantly resupplied by missions from Earth, a costly and timely endeavour that a multinational mission would struggle to accomplish, let alone one nation going it alone. The discovery of water on the Moon, hiding as ice in the shadowed and cold reaches of the deepest lunar craters, raised the very real possibility of a lunar colony being self-sustaining, rather than reliant on resupplies from Earth.

"Water on the Moon is the most important discovery for spaceflight since the rocket equation," explains Dr Spudis. "It means that we can learn how to 'live off the land' on the Moon, an essential skill for any space-faring species."

It's not quite as easy as landing on the Moon and scooping up bucketfuls of water, however. While water ice exists, its quantities are up for debate. The lowest estimates place it at making up just 0.00001 per cent of a portion of lunar soil, sparser than the driest deserts on Earth. Upper estimates suggest a quantity of 8.5 per cent, a much more useful amount if correct. In March 2010, Chandrayaan-1 again made an important discovery, this time finding 40 permanently darkened craters near the Moon's poles with a potential 600 million metric tons (1.3 trillion pounds) of water ice if the upper estimate holds true.

Dr Spudis highlights the need to quantify how much water ice is available to ensure the success of a lunar colony: "Although we know that water exists on the Moon, we have many questions about its physical state and how it varies in concentration. We need to prospect and map ice deposits, extract some water to determine how difficult it may be, and use it in space to completely demonstrate the use of lunar water from an end-to-end systems engineering basis."

Whatever the true quantity of water on the Moon, the possibility of colonising the Moon is not only exciting but also incredibly useful. From a purely financial perspective, the prospects might seem bleak. Estimates suggest a lunar colony would cost upwards of tens of billions of dollars, an amount of money simply not available to any space agency in the world. But the potential returns are huge, in the form of job creation, new inventions and better technologies. For every dollar invested in the Apollo mission, it is said that around 20 dollars were returned to the American economy. The prospect of a permanent residence on the Moon would only increase the potential return. And this is before we even consider the existence of helium-3 on the lunar surface, an isotope blasted across the Moon by solar wind that could be the key ingredient to creating fusion reactors, and therefore huge sources of power, on Earth.

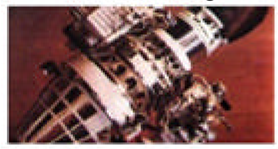
Humanity is not just a species driven by money, though, despite what some would have you believe. We are inquisitive, curious, and we constantly strive to further understand the natural world around us and the universe as a whole. Confining ourselves to our world and failing to invest in manned space exploration would be akin to giving up on our natural habits, to learn, and would relegate us back to an age where humans merely looked upon the stars with fondness, rather than the thought that they could be explored.

"Technically, we're not far away from returning man to the Moon and creating a Moon base"

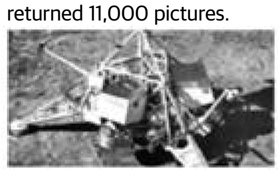
Dr Paul Spudis, senior staff scientist, Lunar and Planetary Institute

History of Moon exploration

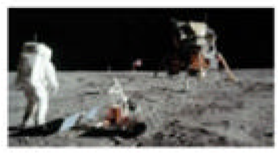
3 Feb 1966
Luna 9
This Soviet 'craft was the first probe to land on the Moon and return surface images.



30 May 1966
Surveyor 1
The first successful unmanned American Moon landing returned 11,000 pictures.



20 July 1969
Apollo 11
Neil Armstrong and Buzz Aldrin were the first humans to set foot on the Moon.



11 Dec 1972
Apollo 17
While the last humans on the surface were Americans Gene Cernan and Jack Schmitt.

22 Aug 1976
Luna 24
This was the last spacecraft to date to land on the Moon and return lunar samples to Earth.

8 Nov 2008
Chandrayaan-1
This Indian probe found water on the Moon, and released an impactor to the surface.

A small step – developing lunar bases

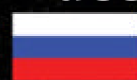
While NASA has long had a vision to create a manned station on the Moon, other agencies have also announced plans to return humans to the Moon for a prolonged period of time.

China

The biggest emerging nation in space exploration, China has made no secret of its desire to land humans on the Moon. It launched its first two unmanned probes in 2007 and 2010, with the third set to follow in 2013.

It has also carried out extensive manned operations in Earth orbit, with a manned space station to follow in the coming years. All of this is building towards a manned lunar landing and, possibly, a permanent residence on the Moon.

Russia



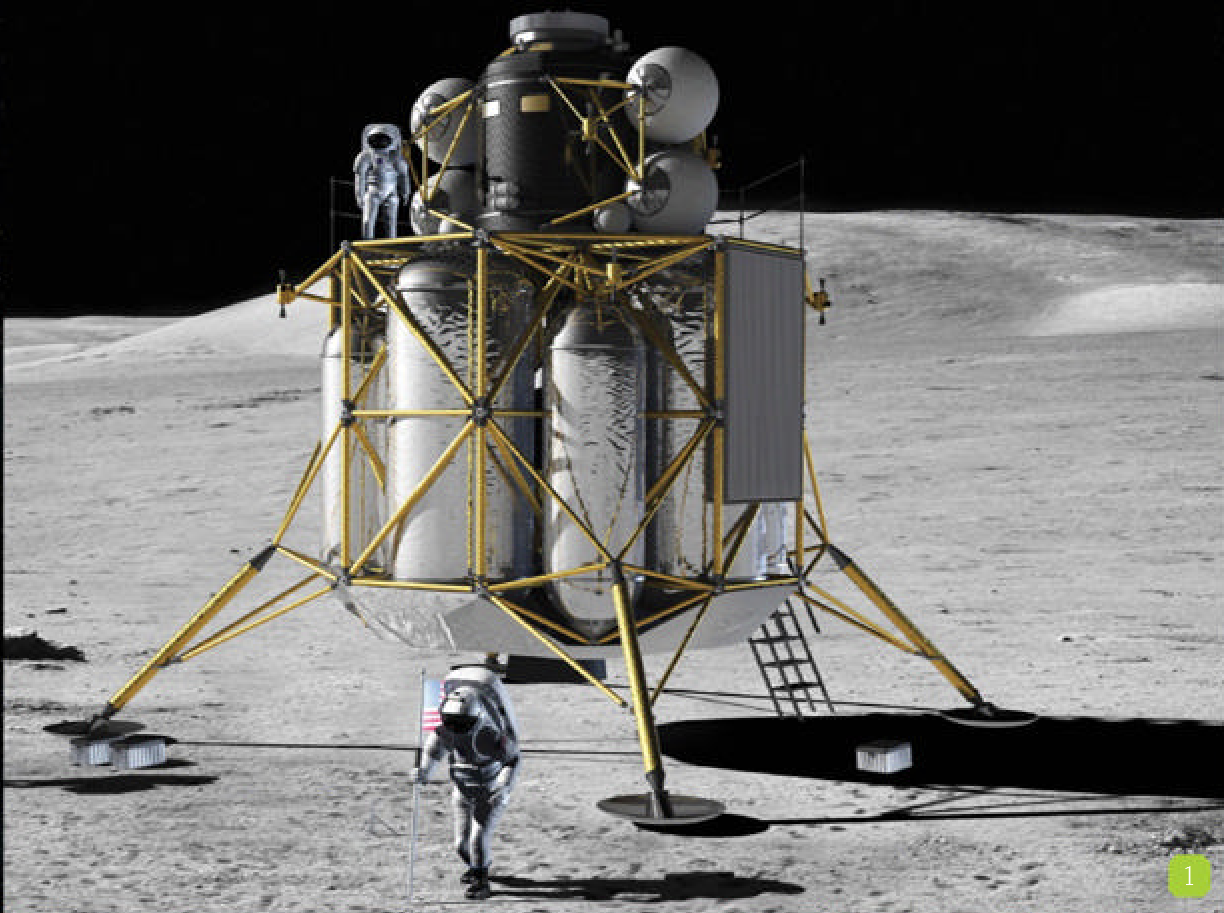
Roscosmos, the Russian space agency, has a number of unmanned landers planned to touch down on the lunar surface by the end of the decade, but work is also underway on a manned mission that will take Russians to the Moon for the first time. Four automated probes will land on the Moon by 2020, followed by a larger station in 2023. This station could be the first part of a manned lunar base in a polar region to follow at an unspecified date.

India

The Indian Space Research Organisation (ISRO) has announced rather lofty goals for space exploration, including a manned landing by 2020. While this looks unlikely for now, its intentions to return man to the Moon at some point are clear.

Japan

The Japanese Aerospace Exploration Agency (JAXA) has suggested that it wants to build a robotic base on the Moon by 2020. This would be a precursor to a manned lunar base in 2030.



USA

Since the Apollo missions ended, NASA has been studying the feasibility and usefulness of returning humans to the Moon. The discovery of water ice has provided the added incentive that could result in the construction of a lunar base.

In September 2012, NASA deputy chief Lori Garver announced the agency's ambitions: "We're going back to the Moon, attempting a first-ever mission to send humans to an asteroid and actively developing a plan to take Americans to Mars."

NASA has carried out a lot of research into lunar habitation. From rovers to landers, it has tested important technologies that we'll need to return to our natural satellite.

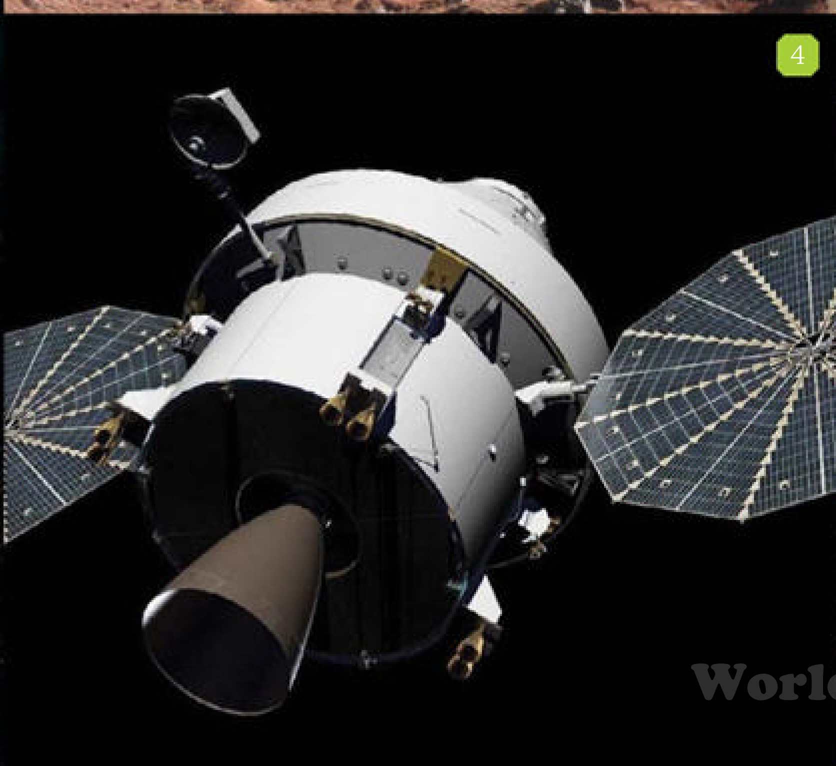
1. Altair lunar lander
Now scrapped, Altair was once part of NASA's cancelled Project Constellation.

2. Lunar Electric Rover
This vehicle could house two astronauts at a time, and enable them to perform space walks on the Moon.

3. Project Morpheus
This automated NASA cargo vehicle, currently in the testing phase, would be used to transport up to 500kg (1,100lb) of cargo to the lunar surface.

4. Orion
The Orion Multi-Purpose Crew Vehicle could take man beyond low-Earth orbit to the Moon. It is also intended to be used to visit an asteroid and Mars.

5. Inflatable habitats
To save space on launch, NASA has been researching the possibility of taking inflatable habitats to the Moon.



The giant leap – future plans for a Moon colony

By the end of the 21st Century a colony on the Moon is a realistic possibility. The technology for each component, from inflatable habitats to transport to and from the Moon, is already in development. Once we work out how to harness some of the Moon's most useful resources, settling on the lunar surface will become an attractive goal.

Rovers

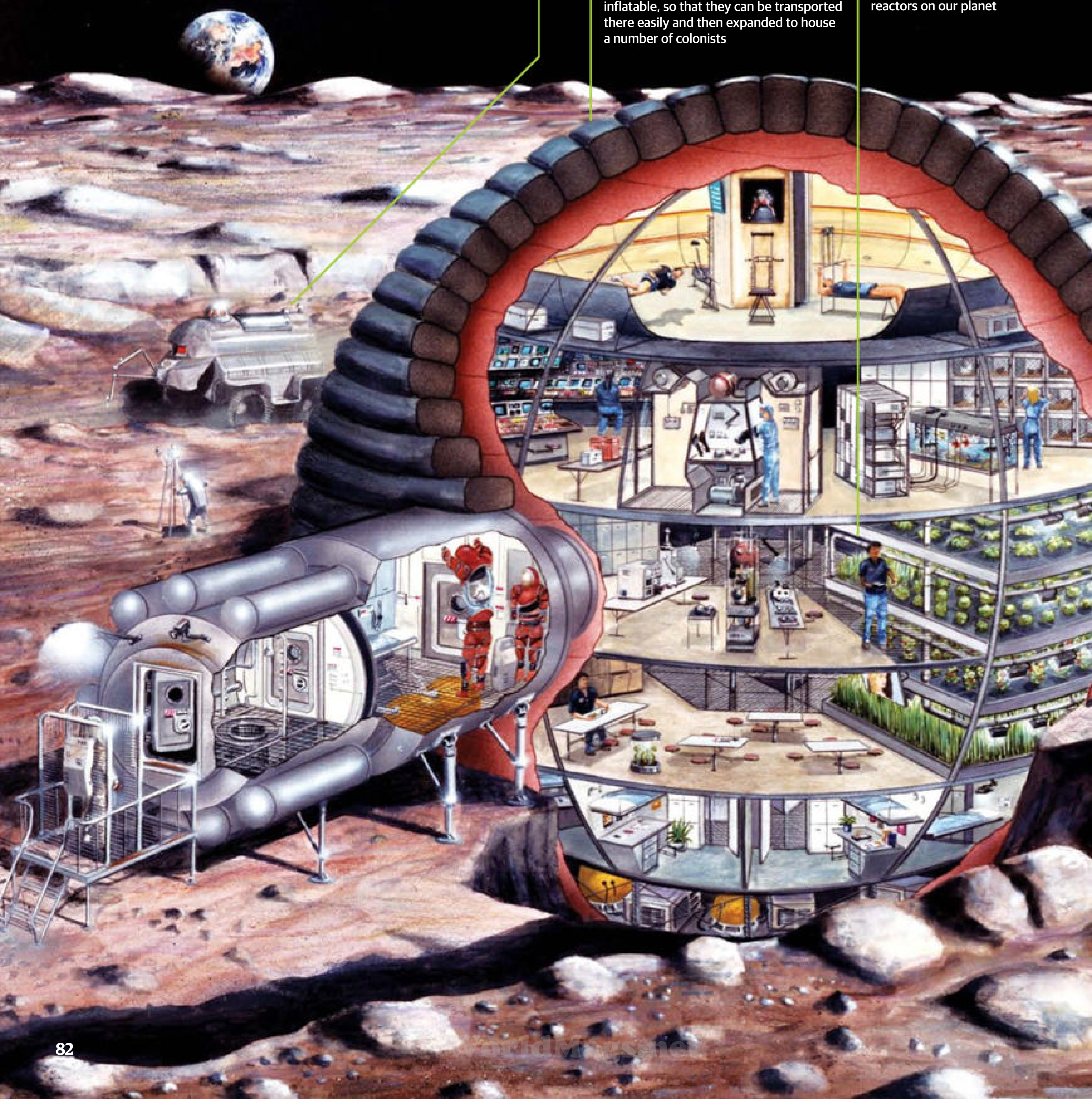
In order to explore vast swathes of the Moon, including water-rich craters, manned and unmanned rovers will be a necessity. Manned rovers could be mini habitats, allowing astronauts to survive on excursions away from the base for several weeks

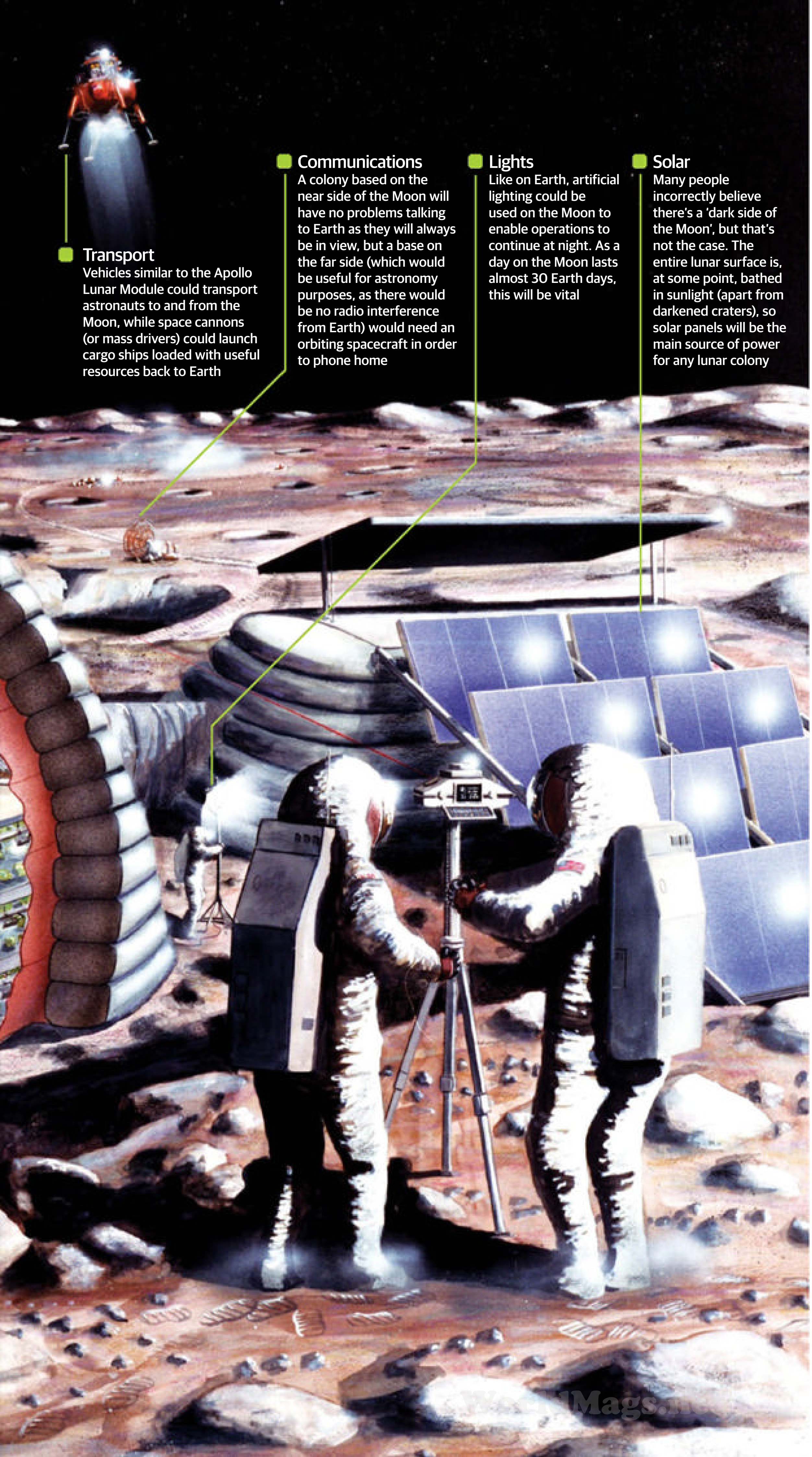
Inflatable stations

Habitats on the Moon will likely be inflatable, so that they can be transported there easily and then expanded to house a number of colonists

Resources

Both water and helium-3 are the most useful resources on the Moon. Apart from drinking, the former could be used by the colonists to create fuel on the Moon, while the latter could be launched back to Earth to power futuristic fusion reactors on our planet





Privatising the Moon

The best way to colonise the Moon might be to realise the commercial benefits of it, space settlement expert Al Globus told us. Globus has previously worked on the ISS from Earth and, alongside being chairman of the National Space Society's Space Settlement Advocacy Committee, he is a big proponent of space settlement and has written many papers on the subject.

By the end of the 2010s, Globus said, governments around the world will have a number of landers and orbiters on and around the Moon. The big change in manned space exploration, however, will be the huge growth of the private sector. Sub-orbital tourism (with the likes of Virgin Galactic) will take-off, with over 1,000 people a year reaching space by 2020.

The next two decades will see lunar mining companies begin to spring up on the Moon, he continued, although they could struggle financially at first. The key for their success will be the growth of the space tourism industry; even though the ISS will be decommissioned in the early 2020s, space hotels will be launched into Earth orbit and expand the private space sector. Over the next 50 years the number of space tourists could grow to millions, not just thousands.

This, Globus said, is where privatising the Moon will be key. Mining resources from the lunar surface, such as water, could provide essential supplies for these hotels. It'll take a while for lunar mines to become profitable, but by the 2070s they could be supplying most of the materials necessary for space hotels.

Furthermore, if NASA or another agency constructs a lunar mass driver on the Moon, which would allow for cargo to be sent back to Earth, then Globus said the lunar mining business will become extremely profitable, allowing it to potentially dominate the metal markets on Earth. In the 2050s these mines would need a crew of just 20 people, but by the 2080s there could be thousands of people living on the Moon and operating them.


Could this be the construction site of tomorrow?


The Apollo missions returned a lot of useful lunar rock

The colonisation of the Moon is a vital stepping stone in our grander scheme of exploration.

That's not to mention the constant threat our planet is under from extinction. It's easy to forget that just 65 million years ago, a mere 1.4 per cent of our planet's 4.5 billion year existence, an asteroid wiped out almost every living thing on the surface. We know that there's no impending impact event, but one is likely to occur at some point. With no other-world colonies to inhabit, we are doomed to extinction.

"The Moon serves as our first 'off-shore coaling station' on the ocean of space," agrees Dr Spudis. "We can use its material to fuel a permanent transportation system, one that allows us to not only access the Moon and explore it in detail, but more importantly, to routinely access all of cislunar space [the zone between the Earth and the Moon], where all of our satellite assets reside. The Moon is also a major scientific resource because it records in detail a period of Solar System history that has been erased from the Earth."

So, if we were to decide to build a lunar colony, could it be done?

> "From a policy perspective, we are light years away, mainly because few people recognise the value of the Moon" **Dr Paul Spudis**

"Technically, we're not far away from returning man to the Moon and creating a Moon base at all," says Dr Spudis. "We have all the individual pieces and technology we would need to live and work on the Moon right now." Technology, however, is not the problem, explains Dr Spudis: "From a policy perspective, we are light years away, mainly because few people recognise the value of the Moon as I have described it here. I am trying to change those misperceptions."

Many agencies have carried out studies into the feasibility of a lunar colony, reaching as far back as 1959 when the US Army first established a plan to build a fort on the Moon with two astronauts. Known as Project Horizon, it would have required about 150 separate rocket launches, making it unattractive from a cost perspective.

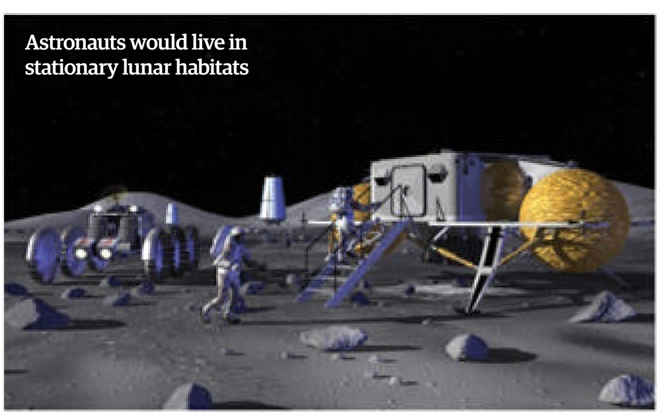
Various proposals have followed, and in the 21st Century numerous countries have at least announced their intentions to build a base on the Moon, including Japan, Russia and the USA. It is NASA, however, that has carried out the most research in the area. For example, it has been testing its Lunar Electric Rover for several years now and, while it might be repurposed for use on an asteroid rather than the Moon, it could provide weeks of habitation for astronauts on the Moon if deployed.

All forms of research, though, have focused on visits longer than the Apollo missions (so over three days) but not quite at a level of permanent habitation. As Dr Spudis explains, we still have problems to overcome if we are to colonise the Moon. "Although we understand how to extract and use lunar resources in theory, we have not done so in practice," he says. "The biggest need right now is experience: in accessing and surveying the ice deposits, in digging up the ice and processing it into water, in converting that water into its gaseous components, in cryogenically freezing the gases into liquids and, finally, using the product in a variety of applications. We understand how to do all these things in theory, we simply need to learn to do them to learn where the problems are."

Overcoming these problems and testing key technologies are imperative goals if we are to achieve the ultimate dream of building a settlement or colony on the Moon. There's little doubt, however, that positive progress is being made in many of the necessary areas by several nations around the world.

Lunar colonies are not just the fancy of space visionaries any more; they will certainly play a useful and important role in our continued future exploration of the Solar System, and provide us with an off-world habitat the likes of which have never been seen before. "I believe that the Moon is a critical enabling step into the Solar System," says Dr Spudis. "It is a stepping stone to space capability." ●


Manned and unmanned vehicles could scour the Moon's surface


Astronauts would live in stationary lunar habitats

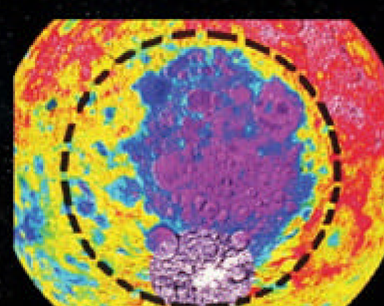

Many different components are needed for a lunar colony

Road map to the Moon

NASA Johnson Space Center engineer John Connolly speculates on how he thinks lunar colonisation might develop.

2010-2019

Leading up to the year 2020, the first private lunar lander will land on the Moon, likely to claim the Google Lunar X Prize. This may open up an entire new way of performing lunar science missions – with science agencies purchasing 'rides' for their instruments rather than funding the engineering of the spacecraft and purchase of launch vehicles. Lunar sample return missions will date the deepest known impact basin (South Pole-Aitken basin) and return samples of polar volatiles. Other robotic missions will probe the permanently shadowed craters of the lunar poles and test in-situ resource utilisation technologies



2020-2029

In the 2020s humans will return to the Moon. Lunar surface missions will become international partnerships, following on from the experience of the ISS, and multiple countries will raise their flags on the Moon. We will test in-situ resource utilisation at human-scales, producing water and propellants from lunar feedstock

2030-2039

The 2030s will see a continued buildup of an international science base near one of the lunar poles. 30-day missions with crews of four will mature to 180-day missions in which teams of pressurised rovers carry crews to more remote sites. Lunar resources will be in full use to provide the crews' oxygen, water, and the propellant for their return to Earth. The lunar surface will increasingly be used to test hardware that will be used for an upcoming human mission to Mars. In lunar orbit, or perhaps at an Earth-Moon libration point, the deep-space habitats and propulsion systems for the Mars mission will also be tested. The first lunar tourists will likely arrive in this decade

2040-2049

Scientific exploration of the Moon begins to combine with commercial visits. Interest in lunar metals and resources fuels commercial missions to produce not only fuels and consumables to support lunar operations, but to extract high-value materials for export to Earth. Helium-3 mining, which occurs as a by-product of other resource extraction processes, reignites the interest in nuclear fusion as a clean power source for Earth

2050-2059

Lunar colonies begin to spring up at multiple locations around the lunar globe. 'Vacations' to the Moon, though still costly, become the top destination, with lunar 'hotels' beginning to emerge. The first child is born on another world

2060-2069

Colonisation begins to increase, with distinct communities occupying different parts of the Moon. Like the Antarctic of 100 years earlier, different countries have established permanent outposts for scientific purposes, but other areas are being developed for commercial resource purposes and for residential communities

2070-2079

The Moon becomes the stepping off point for human voyages to Mars and beyond. Due to its rich resources, and low gravity, the Moon becomes the choice for launching missions into deep space

Awesome impact craters

Our own planet has taken a beating from space rocks in its past, but it's nothing compared to the massive asteroids that have pummelled our nearest neighbours

The Moon: South Pole-Aitken basin

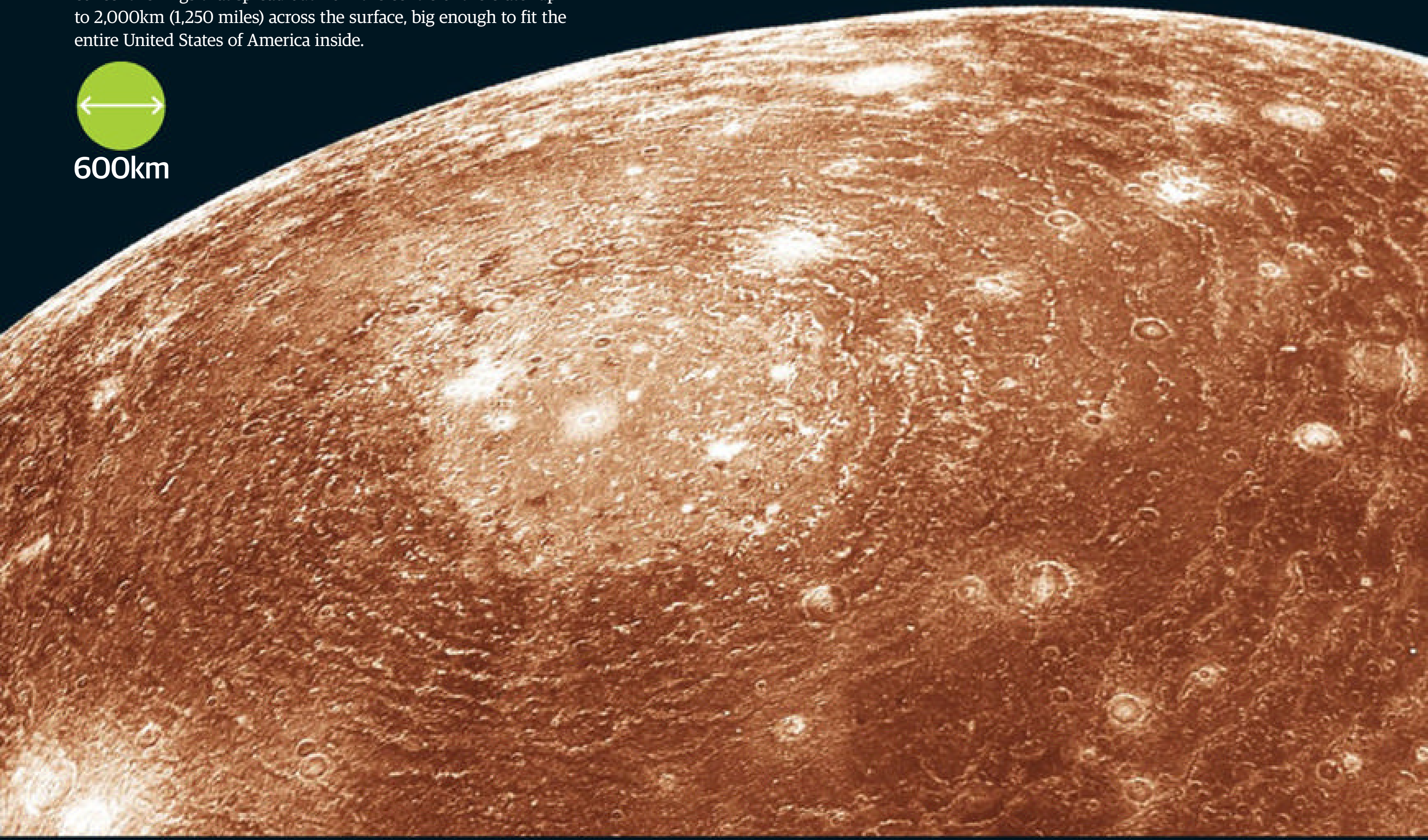
On the far side of the Moon is an impact crater with a diameter equivalent to the distance between London and Athens. The massive Aitken basin measures around 2,500km (1,600 miles) across and is the largest, deepest and oldest basin on the Moon. In fact, it's as deep as 6km (3.7 miles) in some places. For comparison, some of the largest impact craters on Earth are only several hundred metres deep. The Aitken basin is thought to have formed about 4.3 billion years ago.

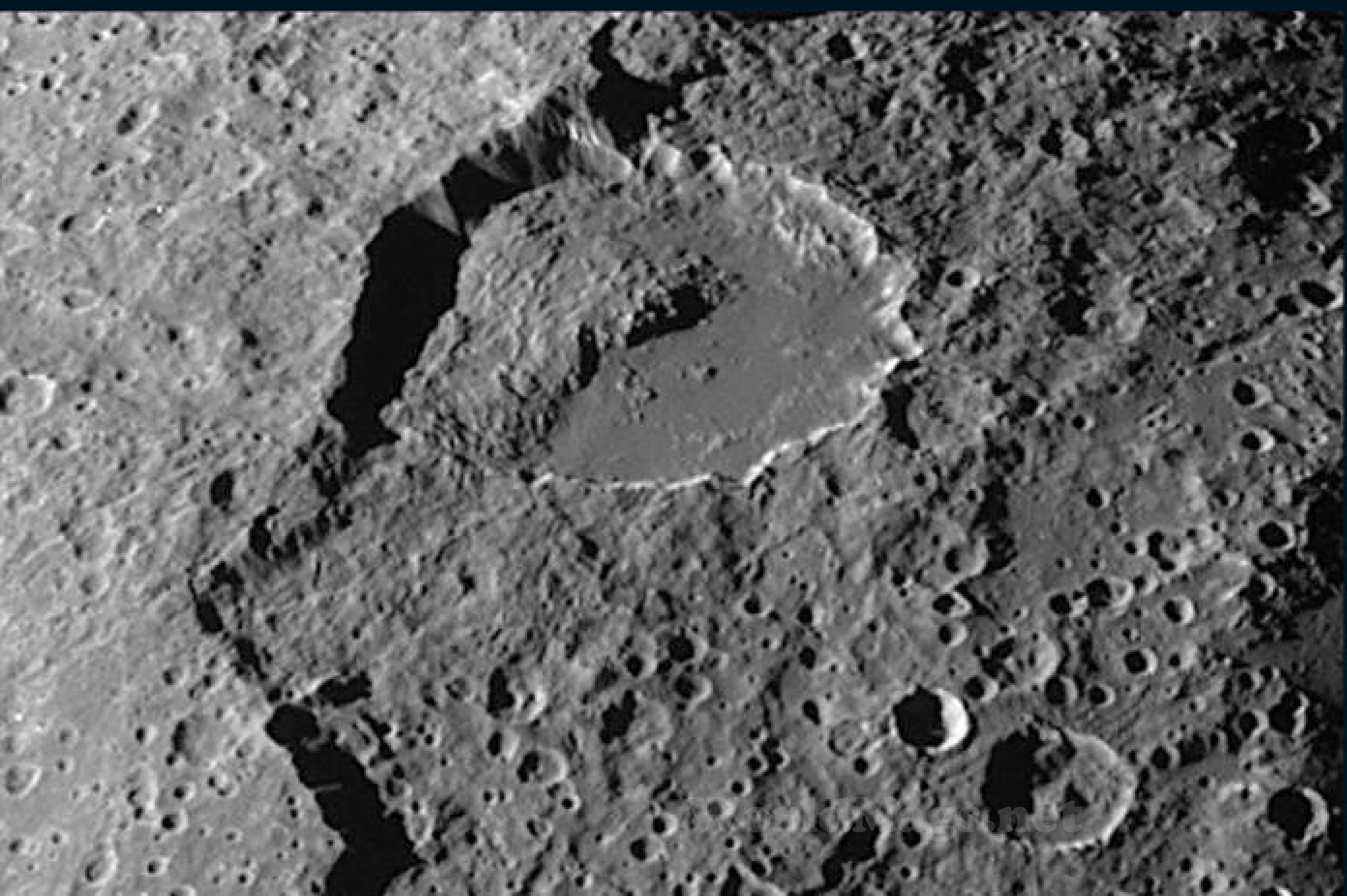
Its origin, however, remains a mystery. If it formed through a high-velocity impact then scientists would expect to find material from deep within the Moon's mantle at the bottom of the basin, but this doesn't seem to be the case. Instead, it's thought that a low-velocity projectile hundreds of metres across impacted the Moon at an angle below 30 degrees, enough to create the giant crater but not fast or steep enough to dig deep into the lunar surface.

Callisto: Valhalla

Jupiter's moon Callisto plays host to the largest multi-ring impact crater we know of. Valhalla is made up of a bright central zone around 600km (370 miles) across. The initial impact, however, appears to have fractured the surface of the moon and created concentric rings that spread out from the centre of the crater up to 2,000km (1,250 miles) across the surface, big enough to fit the entire United States of America inside.

600km





Iapetus: Turgis

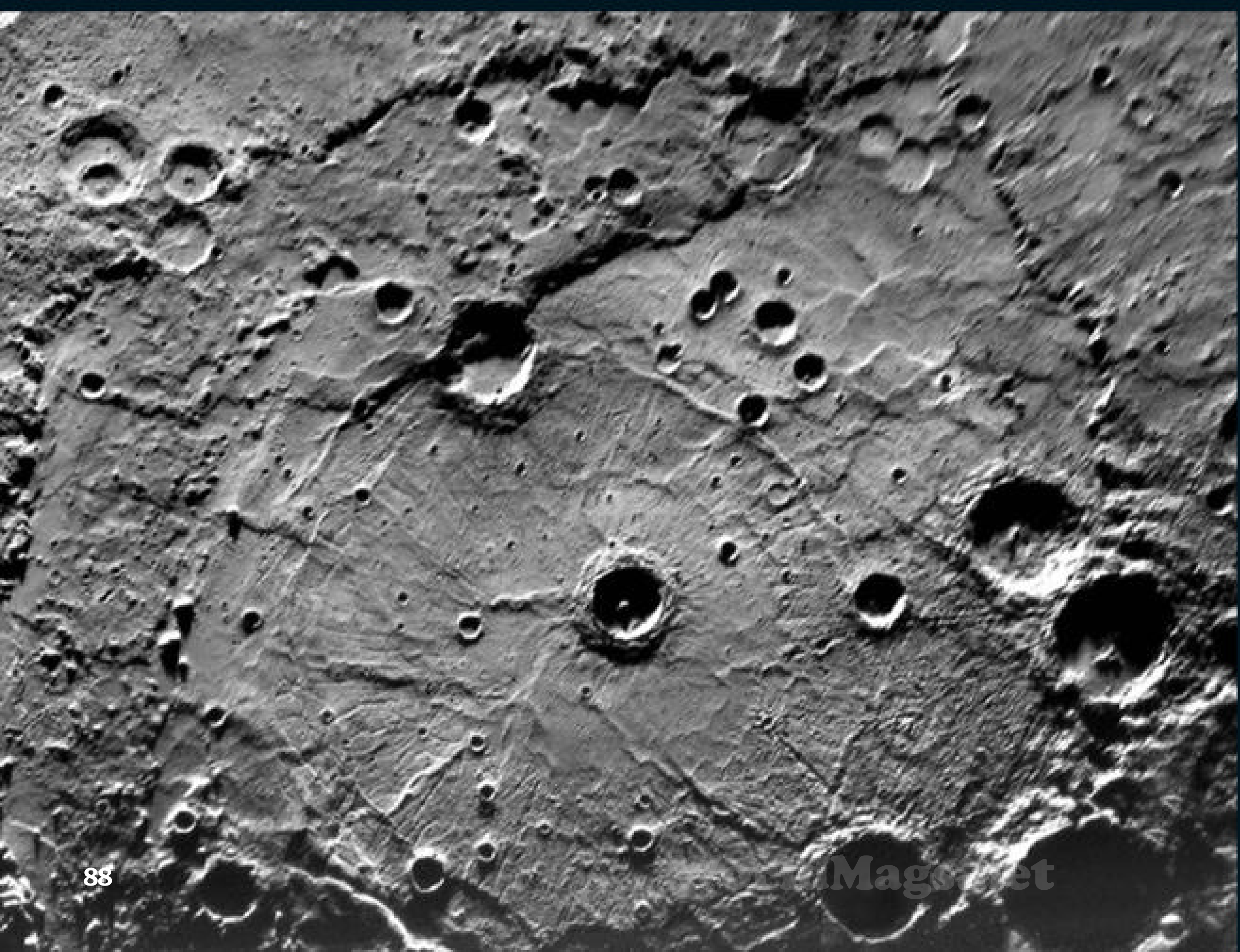
Iapetus is one of Saturn's most bizarre moons, boasting a strange two-toned colouration and a giant equatorial ridge. It also plays host to a crater 580km (360 miles) wide called Turgis. While it's not the biggest crater in the Solar System, in comparison to the diameter of Iapetus (1,500km or 930 miles) it's massive, making it one of the largest craters in proportion to the size of the celestial object it resides on.

580km

Tethys: Odysseus

Named after the Greek hero of the same name, Odysseus is the largest crater on Saturn's moon Tethys. It was discovered in September 1981 by NASA's Voyager 2 spacecraft and measures 445km (275 miles) in diameter, about two fifths of the moon's diameter. It's about 3km (1.9 miles) deep in places with its rim rising up to 9km (5.6 miles) above the crater floor. A variety of cracks in the crust of Tethys from the initial impact spread for hundreds of kilometres from the crater. Odysseus is not as deep as scientists would expect from such an impact, however, suggesting that the crater's interior was once warmer and malleable, and possibly even liquid, allowing for it to flatten out over time.

445km



Mercury: Rembrandt crater

This giant impact basin on Mercury, named after the famous Dutch painter, was discovered by NASA's MESSENGER spacecraft on its second flyby of our Solar System's innermost planet in October 2008. It is thought to have been created by a huge impact event 3.9 billion years ago during the Late Heavy Bombardment period. Its size and the presence of smaller craters both inside it and around its rim suggest that Rembrandt is one of Mercury's youngest craters. Smooth plains inside Rembrandt suggest that Mercury had an active and volcanic past.

715km

Mars: Hellas Planitia

The largest visible impact crater in the Solar System is Hellas Planitia on Mars, a giant depression with a floor over 7km (4.3 miles) below the Martian surface and a diameter of around 2,300km (1,400 miles). Such is its breadth and depth that you could fit every Western European country inside it. The crater is thought to have formed about 3.8 to 4.1 billion years ago when Mars was hit by a number of objects during the Late Heavy Bombardment period in the Solar System.

Within the crater there are a number of fascinating features that might make it an interesting place to visit on a future exploration mission. It contains gullies that would allow for the presence of liquid water if the temperature on the planet rose high enough, owing to their distance below the surface. Radar images from the Mars Reconnaissance Orbiter also suggest that glaciers reside beneath layers of rock and dirt in three further craters located inside Hellas Planitia.

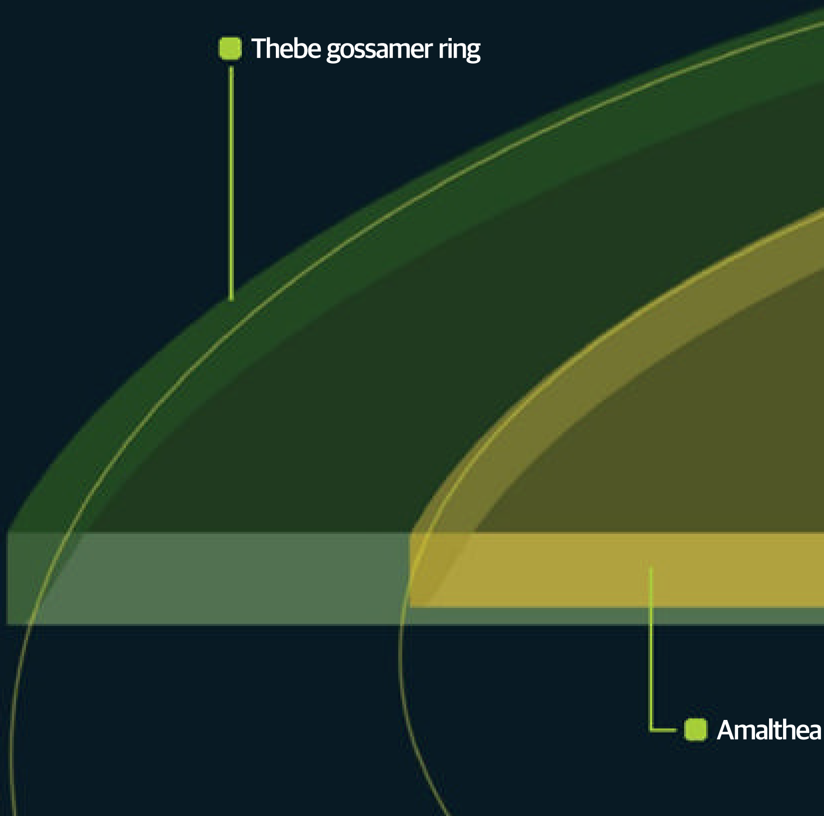
The rings of Jupiter

Did you know that Jupiter has rings like Saturn? Only recently have we been able to study them

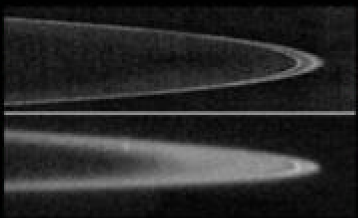
The gas giants Jupiter and Saturn have been known about and observed since ancient history. During the Renaissance period and with the dawn of the telescope, Saturn was characterised by its mesmerising ring system whereas Jupiter was the hulking brute of the Solar System, known for the swirling tempest blooming on its south equatorial belt that was later dubbed the Great Red Spot. Scientists identified a similar ring system on Uranus, so when Voyager 1 began its flyby of Jupiter in early 1979, NASA tasked it to look specifically for rings - and it found some. Nearly 20 years later, the Galileo probe entered orbit around Jupiter and was able to study its rings in detail, while New Horizons was able to take high-resolution images revealing the structure of the main ring in its spring 2007 flyby.

Jupiter's rings are made of four parts and are composed mainly of fine dust of varying grades. A thick 'halo' ring orbits the innermost Jovian region, followed by the bright main ring, and the two faint gossamer rings. These gossamer rings are made up of the dust ejected from the two moons, Thebe and Amalthea, which orbit within them, a result of high-energy impacts kicking up debris from their surfaces. The biggest of Jupiter's rings is the Thebe gossamer ring, which has a radius of around 226,000 kilometres (140,000 miles), a width of 97,000 kilometres (60,000 miles) and a thickness of 8,400 kilometres (5,000 miles).

The rings themselves might have existed as long as Jupiter, although the lifetime of the tiny dust particles in the main ring could be anything from 100 to 1,000 years. It's continuously being removed from the ring by the Jovian magnetosphere and replenished by impacts between larger objects that are anything from a single centimetre (0.4 inches) up to 500 metres (1,640 feet) in diameter.

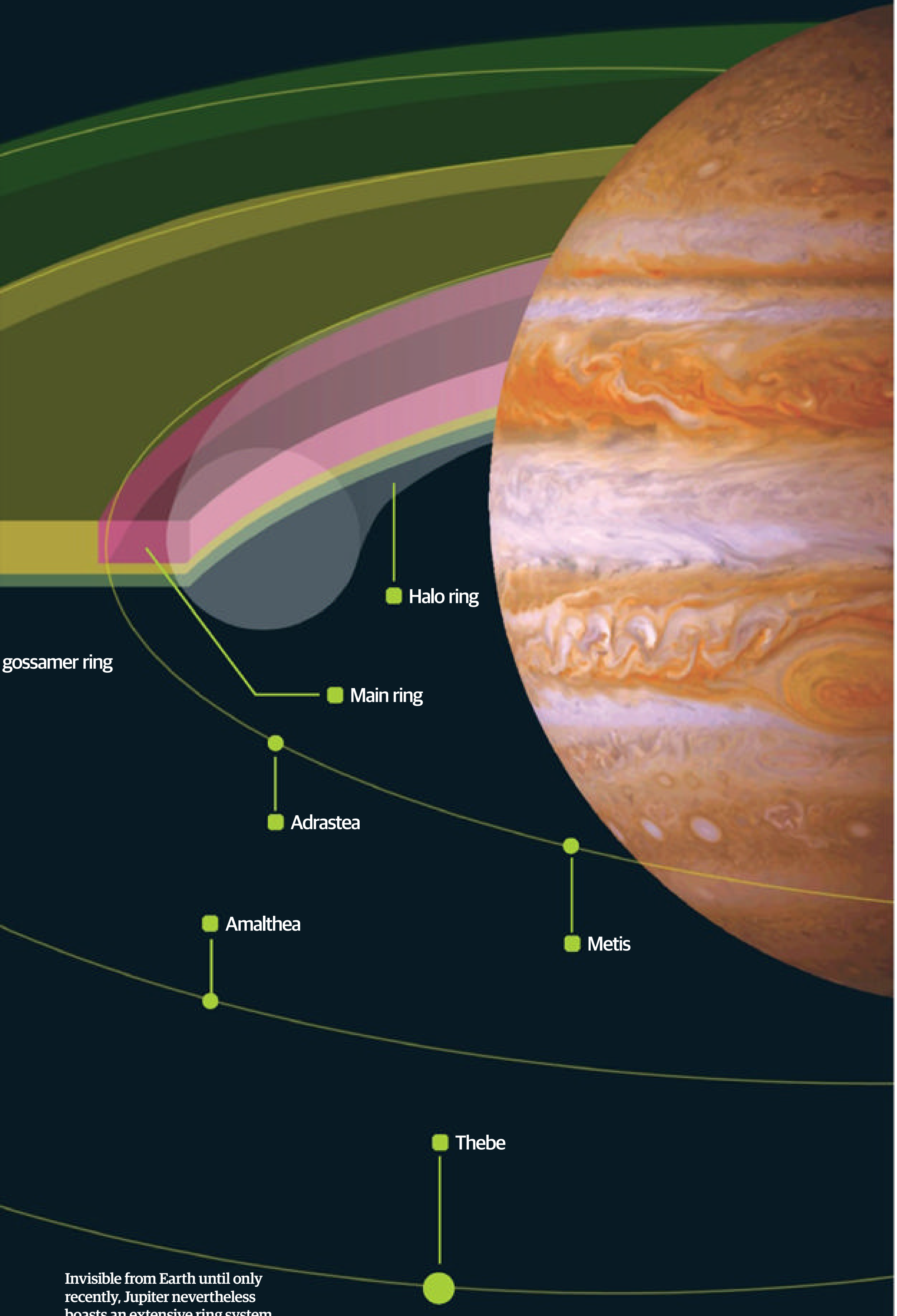


"When Voyager 1 began its flyby of Jupiter in early 1979, NASA tasked it to look specifically for rings - and it found some"



Planetary rings

There are several theories of how large planetary rings of this type are formed. One theory is that they're the remnants of the protoplanetary disc that formed the planet, left within a region that was unable to form a moon (known as the Roche limit). Another is that they're the remains of a moon either torn apart by the tidal stresses of large planets such as Jupiter, or destroyed by a massive impact. Smaller and fainter rings can form from multiple impacts into the surface of moons orbiting a planet or from a volcanic eruption, such as the E-ring of Saturn, which formed out of the cryovolcanic ejecta from Enceladus's volcanoes. In around 50 million years' time, the Martian moon Phobos is likely to be pulled apart into a ring because of its low orbit. Since the discovery of rings around Uranus, Neptune and Jupiter, scientists have been looking closely at other celestial bodies such as the Saturnian moon Rhea and Pluto, to see whether they have rings, too.



Invisible from Earth until only recently, Jupiter nevertheless boasts an extensive ring system

Ring breakdown

What are Jupiter's rings made of, how big are they and how were they formed?

Halo ring

The innermost halo ring stretches from around 92,000km (57,000 miles) to just over 120,000km (78,000) and is the thickest of Jupiter's rings through the vertical. It's shaped like a torus and is significantly less bright than the main ring despite being many times wider and thicker. The dust particles that the Halo ring is composed of are less than 15 micrometres in diameter and are mostly derived from the main ring.

Main ring

This narrow ring is just 6,500km (4,000 miles) wide and stretches from 122,500km (76,000 miles) and 129,000km (80,000 miles). It's the brightest of the rings and fringes on Adrastea, the smallest of Jupiter's four inner moons. The main ring's dusty composition isn't evenly distributed and is divided into regions of varied thickness that scatter light more effectively than the other rings. Still, it was faint enough to be missed by the Hubble Space Telescope and wasn't detected until Keck viewed it in 2002.

Amalthea gossamer ring

The innermost gossamer ring runs from the border of the main ring to around 182,000km (113,000 miles), decreasing in thickness towards Jupiter. The ring gets its name from the Jovian moon Amalthea, a 160km (99 mile) diameter rock that orbits right through the centre of the Amalthea gossamer ring. As it passed through the gossamer rings in 2002, the Galileo spacecraft detected small bodies of less than 1km (0.6 miles) near Amalthea, which are likely the debris caused by numerous collisions.

Thebe gossamer ring

Like Jupiter's other rings, the Thebe gossamer ring is composed of dust from impacts with the Jovian moons. It's the faintest of the rings and stretches far out to the orbit of the moon of Thebe at 226,000km (140,000 miles). However, scientists are unable to explain the extension of the Thebe ring's orbit, which could be due to the influence of Jupiter's magnetosphere or even objects on the outside of the Thebe ring that are as yet unseen.

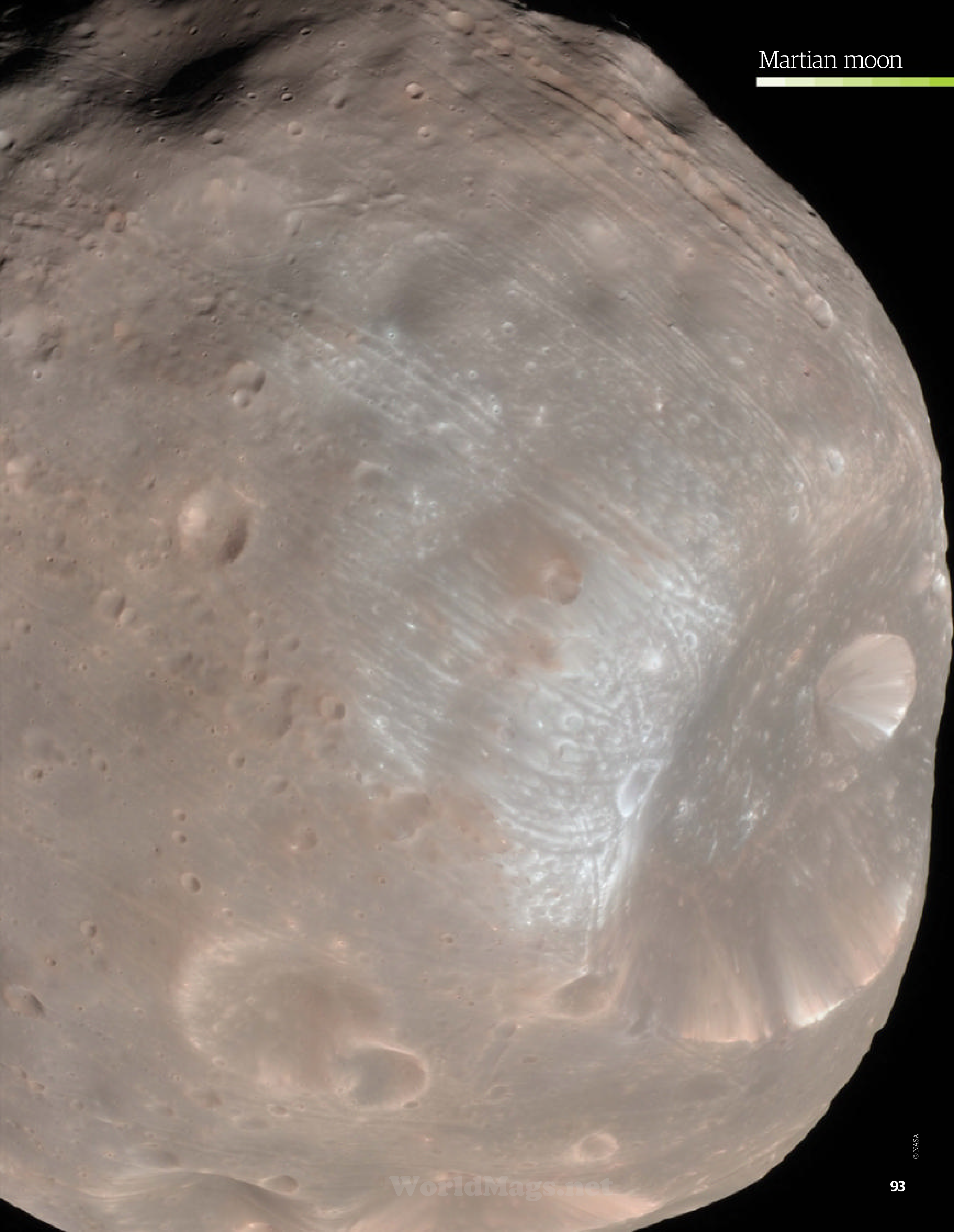
The moon Phobos, shot in visible and near-infrared light by the Mars Reconnaissance Orbiter in 2008

Martian moon

Looming very close: the biggest of the Red Planet's two natural satellites is snapped by an orbiter

NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft entered into orbit around Mars last month and while it does have an ultraviolet imager, it has no camera. It doesn't need one for its mission, which is ultimately to determine what happened to the Red Planet's atmosphere. Fortunately, it's not alone out there around 225 million kilometres (140 million miles) away from Earth and in an orbit that takes it as close as 150 kilometres (93 miles) above Mars.

The Mars Reconnaissance Orbiter (MRO) launched in 2005 and has been snapping away with its camera in multiple wavelengths since March 2006. This stunning close encounter with Phobos took the MRO to within 6,800 kilometres (around 4,200 miles) of this face of the Martian moon, which is around 22 kilometres (13.7 miles) wide. Both the MRO and MAVEN's missions are compatible with each other, and together should hopefully expedite the truth about Mars's mysterious past.



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The geysers of Enceladus fire out water, ice crystals and gases

Giant ice geysers of Enceladus

In 2005, NASA's Cassini spacecraft found huge plumes of water and ice shooting from the south polar regions of Saturn's sixth largest moon. But what are the causes and does it indicate life in our Solar System?

We think of moons as cold, dead satellites for a reason – we've yet to find signs of life anywhere else in our Solar System and a moon seems like the last place we'd look. However, after the Cassini spacecraft examined Enceladus – Saturn's sixth largest moon – we started to think differently.

Enceladus's southern polar region is covered with four or five 'tiger stripes' – parallel depressions in the lithosphere about 500m (1,600ft) deep, more than 100km (62 miles) long and a few kilometres wide. Officially called sulci, these cracks are probably caused by a process called cryovolcanism. Just as volcanoes on Earth spew molten rock, Enceladus is spraying water, ice crystals and gases from geysers located in these cracks.

The vapour shoots out at up to 500m per second (1,600ft per second). The ice crystals come out at about half that velocity while bouncing off the walls of the crevices and landing back on the surface. The question is, what's causing this cryovolcanism and does it mean there could be life on Enceladus?

The simplest explanation is sublimation of surface ice. A definite 'hot spot' (with temperatures up to -116 degrees Celsius or -176 degrees Fahrenheit) was found on the south pole region by Cassini in 2005, which could cause the ice to change quickly into vapour and generate plumes. However, this theory doesn't account for the abundance of geysers and the resulting ice crystals that are deposited on the moon's surface.

Some astronomers believe there's an underground lake or reservoir on Enceladus, with water locked inside ice. The geysers spew lots of ice crystals, which requires a temperature around zero degrees Celsius (32 degrees Fahrenheit). In an underground lake, ice, water and vapour would all mix together. Expanding vapour could escape through the tiger stripes, cooling and causing ice crystals to condense. Where there's a large amount of water, there's the possibility of life. Tiny primitive organisms exist in vents beneath the Earth's oceans, so maybe the same is true for Enceladus.

An alternative theory states that the geysers could be spewing from a layer of liquid water deep below the icy crust. This highly pressurised water is trapped in ice-water shells just below the surface. Some have dubbed this cold geyser model 'Cold Faithful' in an homage to Old Faithful in Yellowstone National Park. These water pockets are heated to about zero degrees Celsius, which would force the plumes of water and vapour to the surface through the tiger stripes. As it passes through colder layers, some of the plume freezes, resulting in the ejected ice crystals falling back down.

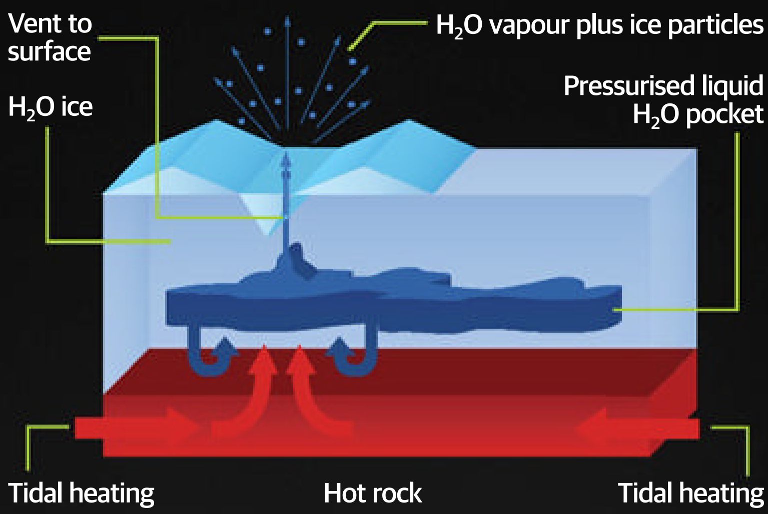
So where is this heat source coming from? Some believe Enceladus has a layer of liquid water far below its icy crust. During Enceladus's revolution around Saturn, the planet's tides

This shot of sunlight over the southern pole of Saturn's moon Enceladus highlights the plumes of ice, water and chemicals spewing from its surface

Theory 1

A planet that runs hot and cold makes for an explosive effect, says one theory

One theory for the cause of these geysers posits that the moon has a much hotter core, which heats highly pressurised liquid water caches just under the surface. When the water gets above zero degrees Celsius (32 degrees Fahrenheit), it jets through the 'tiger stripe' fractures. As the water rises, it passes through layers of ice as cold as -350 degrees Celsius (-598 degrees Fahrenheit), cooling along the way. Jets of water, ice and particles blast through the cracks, with most of the ice landing back on Enceladus's surface.



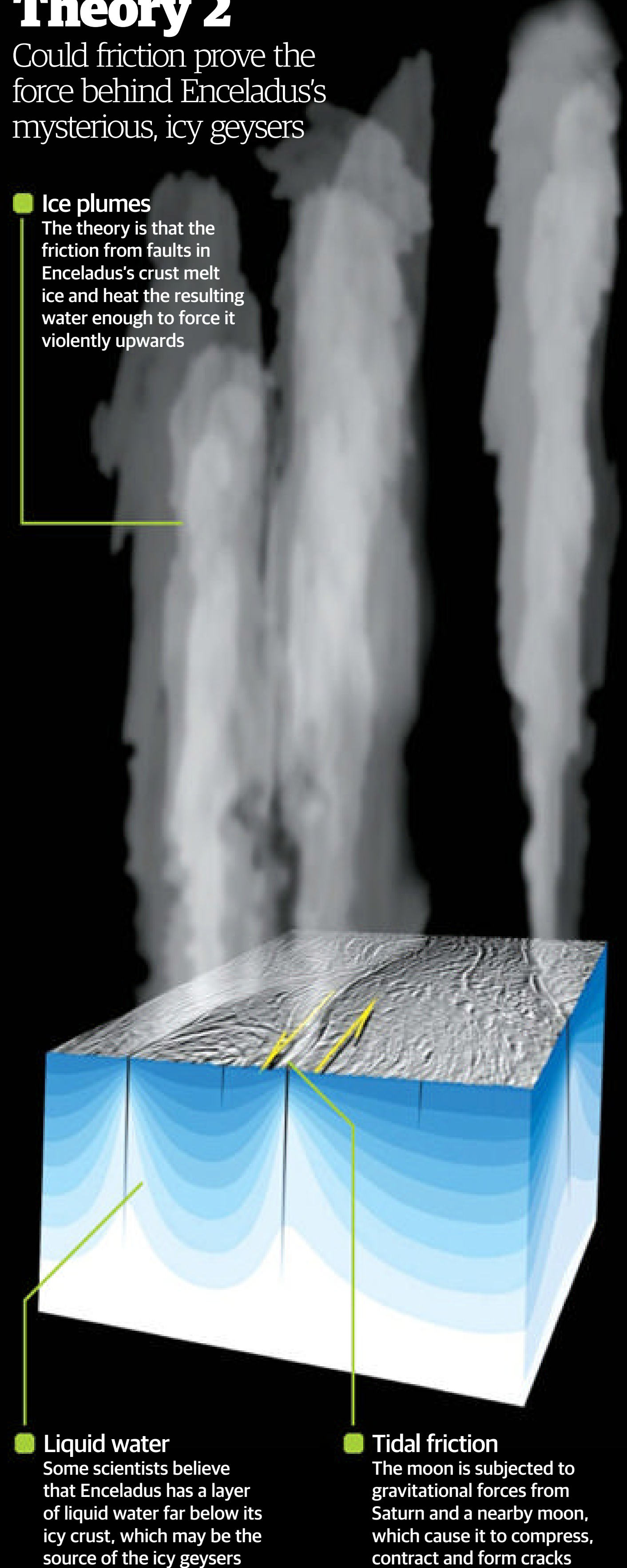
affect the moon, causing it to be squeezed and pulled apart. These forces cause faults on Enceladus to rub against each other and this movement may be as much as half a metre over the tidal period. The resulting friction melts the ice layer into a water layer leading to the cryovolcanic activity. Still further modelling has refined the cold geyser 'Cold Faithful' model into a colder 'Frigid Faithful' model. In this model, the geysers spew due to explosive decompression of clathrates - gases like methane and nitrogen that are trapped in ice-like structures - located just below the surface. A source of heat just 40 degrees Celsius (104 degrees Fahrenheit) warmer than the moon's average temperature could've been enough to cause the icy surface to crack and form the stripes. These cracked shells expose more clathrates to heat, causing the released gases to rush up the vents, taking water and ice with them. If the Frigid Faithful model is accurate, the process doesn't need wild swings in temperature. It also means no underground reservoirs of liquid water, and therefore, nothing to sustain life.

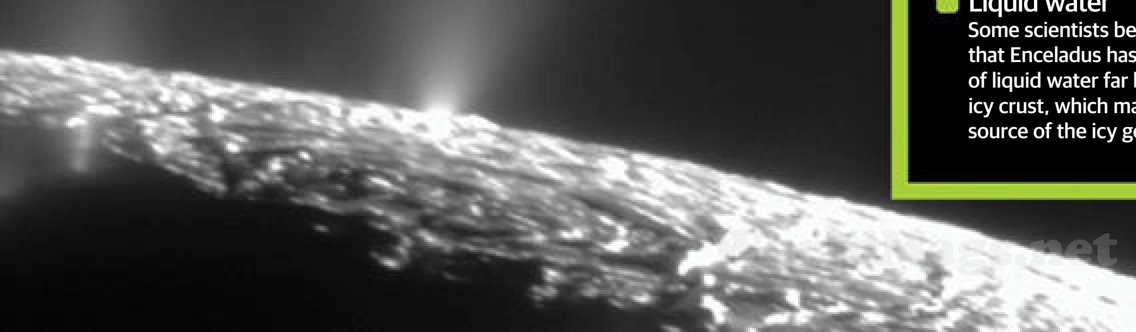
Proponents of the cold geyser model say the Frigid Faithful model doesn't account for the structures that appear to be frozen ice on the moon's surface, which would indicate liquid water. Nor do they explain the high saline content of the plumes close to the moon's surface, which suggests an 'underwater salty ocean'.

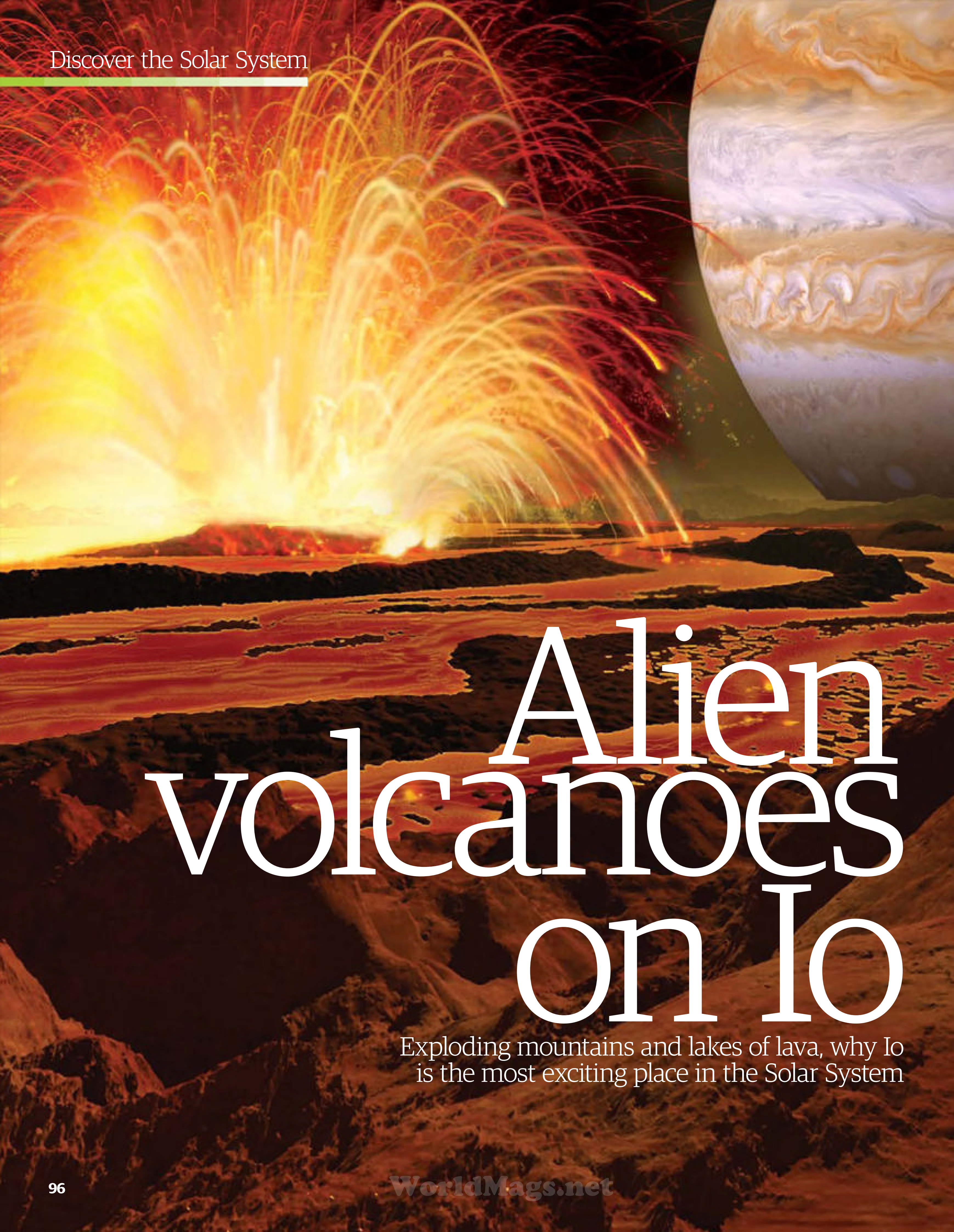
In 2011, scientists announced that this moon is still our best possibility for finding other life in our Solar System. The Cassini mission continues to send back images, but we have much more to learn about its make-up and the cause of its icy plumes before we can determine the true viability of finding life on a frozen moon.

Theory 2

Could friction prove the force behind Enceladus's mysterious, icy geysers

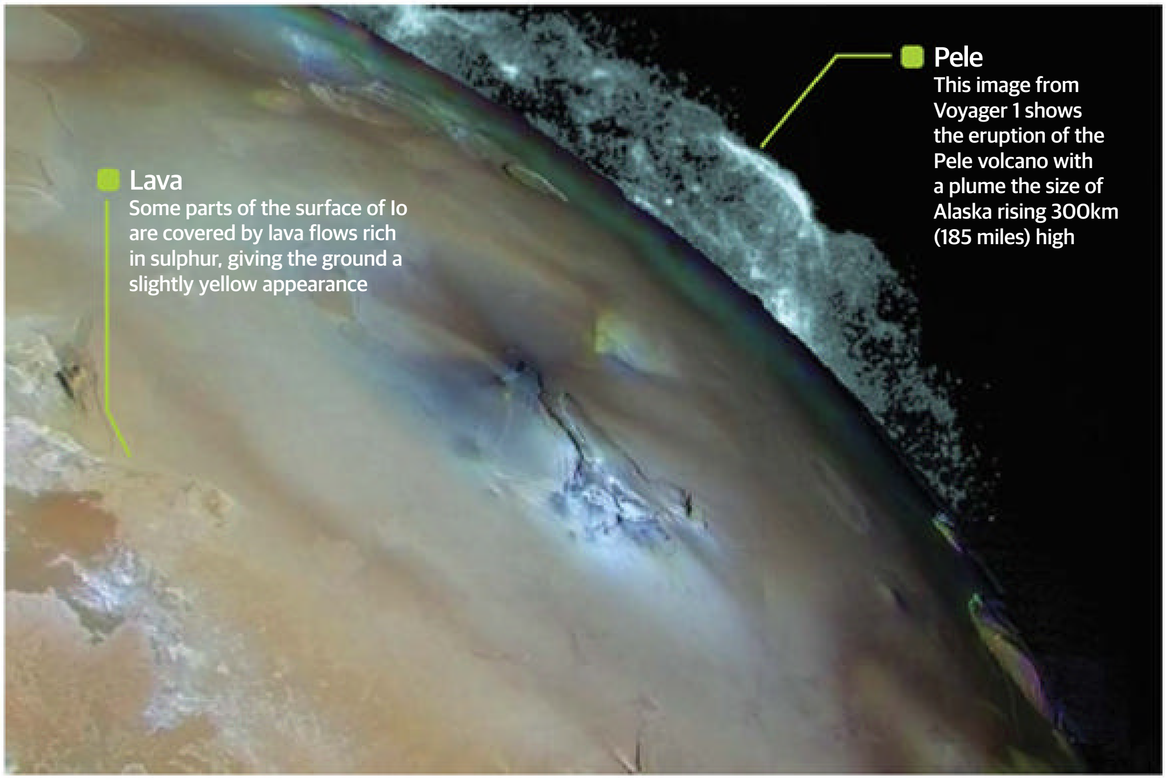






Alien volcanoes on Io

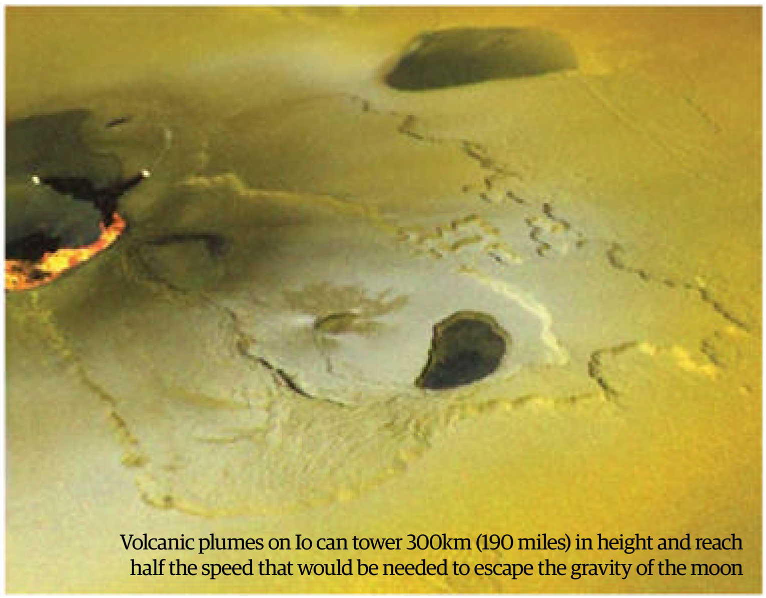
Exploding mountains and lakes of lava, why Io is the most exciting place in the Solar System



In 1979, NASA's two Voyager spacecraft flew by Io, the fourth largest moon in the Solar System and the innermost of Jupiter's four main Galilean moons, and returned some startling information. While moons in the Solar System were once thought to be lifeless hunks of space rock, both spacecraft had directly observed volcanic features on Io. Bearing more resemblance to a pepperoni pizza than a giant moon, it was apparent that Io was one of the most fascinating and significant objects in our Solar System.

Our own Moon is one that appears to have been active in the past but has quietened down to become almost entirely dormant, retaining little to none of the volcanic activity that once sculpted its surface. Indeed only a few planets, Earth included, have changeable environments at all, making the discovery of Io all the more exciting. Where once our Solar System was regarded as an ever-present museum of the past, moons such as this one have proven that it is still a lively and effervescent place. So what is it that makes Io so amazing?

To date, Io has more than 400 known active volcanoes, making it the most volcanically active object in the Solar System, even more so than Earth. Dozens of vents are strewn across its surface leaking gas into the atmosphere, while at its poles and even occasionally close to the moon's equator vast icy plains can be found. The remnants of Io's volcanic past and present are as clear as day, with large volcanic rings the size of California encircling either dormant or active volcanoes.


Volcanic plumes on Io can tower 300km (190 miles) in height and reach half the speed that would be needed to escape the gravity of the moon

While data from the Voyager probes, and later the Galileo spacecraft, has shown us volcanic plumes erupting from the surface of the moon, we are also able to discern some of Io's erupting monsters from observations on Earth. Some volcanoes have even been active for over two decades, meaning that the driving force below Io's surface is even more violent and ferocious than once thought.

The reason for Io's outbursts of activity is that it is being battered and bruised by Jupiter and its other moons. Io sits at a distance of 420,000 kilometres (260,000 miles) from Jupiter, which might sound quite far away but consider that our own Moon sits 385,000 kilometres (240,000 miles) away from us and that Jupiter is almost 318 times more massive than Earth, while Io is almost exactly the same size as our Moon. For this reason it's obvious that while the Earth exerts a small but noticeable force on the Moon, causing it to become gravitationally locked to our planet only a billion or so years ago, Jupiter is exerting a huge force on Io. This moon, which itself is gravitationally locked to

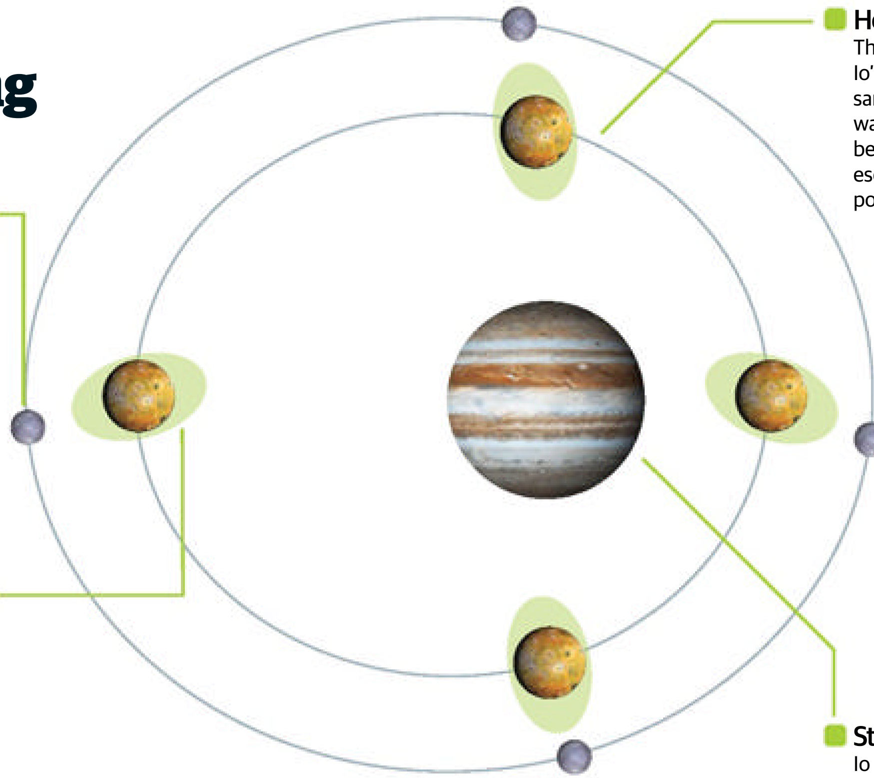
Jupiter, is being constantly pushed and pulled by the huge gas giant, which in turn is churning its insides. Add into this that the other three Galilean moons, of which Io is the second smallest but the closest to Jupiter, also exert a gravitational influence on the poor moon, and you might start feeling sorry for this troubled space rock. The influence of the other moons means that Io's orbit around Jupiter is eccentric, with a difference of 3,400 kilometres (2,100 miles) between its closest and furthest points. So, even though the same face always points towards Jupiter, Io experiences huge changes in gravitational force from this big bully of a planet.

In fact, the force on Io is so intense that its solid surface acts in a similar manner to oceans on Earth. It bulges up and down by as much as 100 metres (330 feet) in places, compared to 18 metres (60 feet) for the highest tides on Earth. Bear in mind that Io's tides are made of solid rock and those on Earth are made of water, and you might realise just how tough a time this moon is having.

These tidal forces create a huge amount of heat in Io's interior, and therefore the majority of its subsurface crust is a liquid. This liquid is under intense pressure and looks for any escape route possible out onto Io's surface, be it in the form of a volcano, geyser or vent. This makes the surface a constantly changing place, with plumes of sulphur dioxide snow ejecting all over it. Any meteorites that hit the moon instantly see their impact craters filled with lakes of molten lava from the interior. The composition of this lava is still somewhat of a mystery but the two main theories suggest that it is either made from various compounds of molten sulphur or silicate rock. The former would account for the odd colouring of the moon, while the latter would better explain the hot temperatures under the surface where it may be too hot for sulphur to exist.

As more missions are sent to the Jupiter system we will learn more about this fascinating and mysterious moon. NASA's solar-powered spacecraft Juno, which launched in August 2011, will enter orbit around the largest planet in our Solar System in July 2016. This will be followed by the ESA's Jupiter Icy Moon Explorer, which is set to launch in 2022 and arrive at Jupiter in 2030.

Tidal flexing on Io



Europa
Io's orbit is not circular due to the gravity of neighbouring moons Europa and Ganymede

Elliptical
Because of its elliptical orbit, Io is stretched and twisted over regular time periods

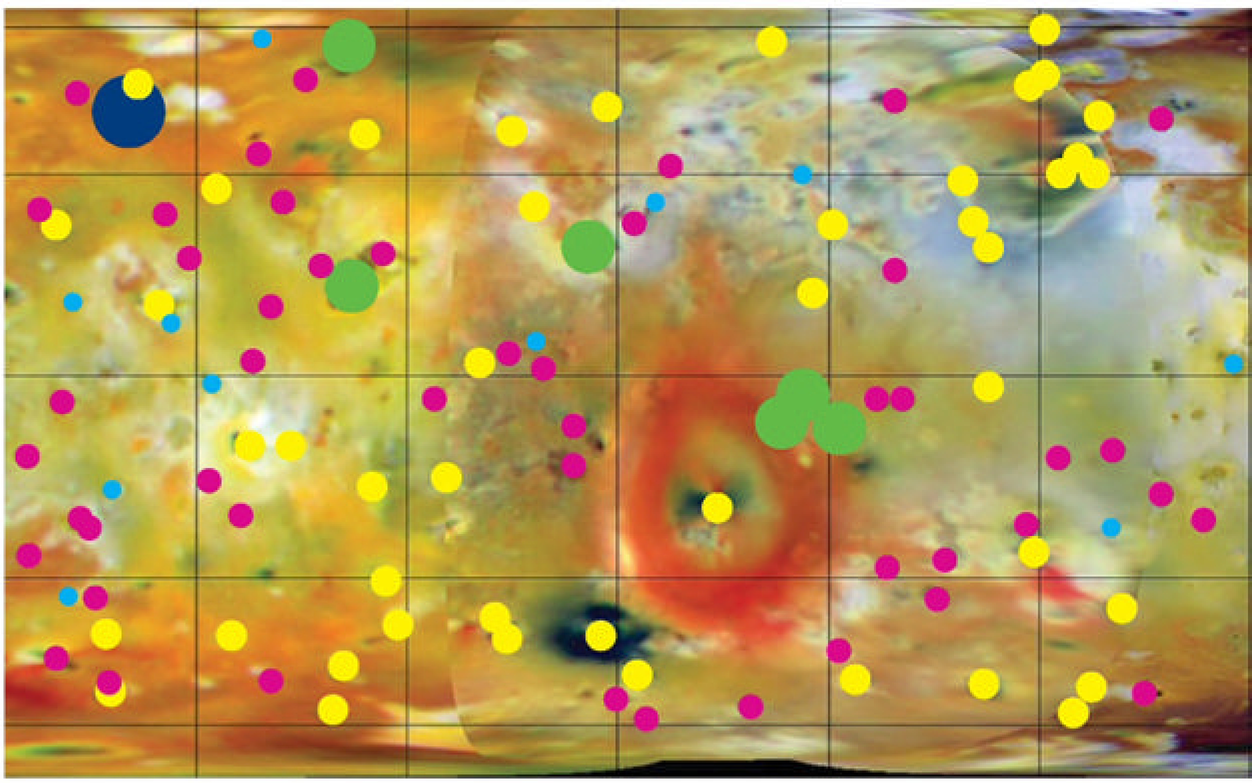
Heat
The tidal flexing heats Io's interior in the same way a paperclip warms when you bend it. The heat escapes through powerful eruptions

Stretched
Io experiences more tidal stretching from its host planet than our own Moon due to Jupiter's massive size

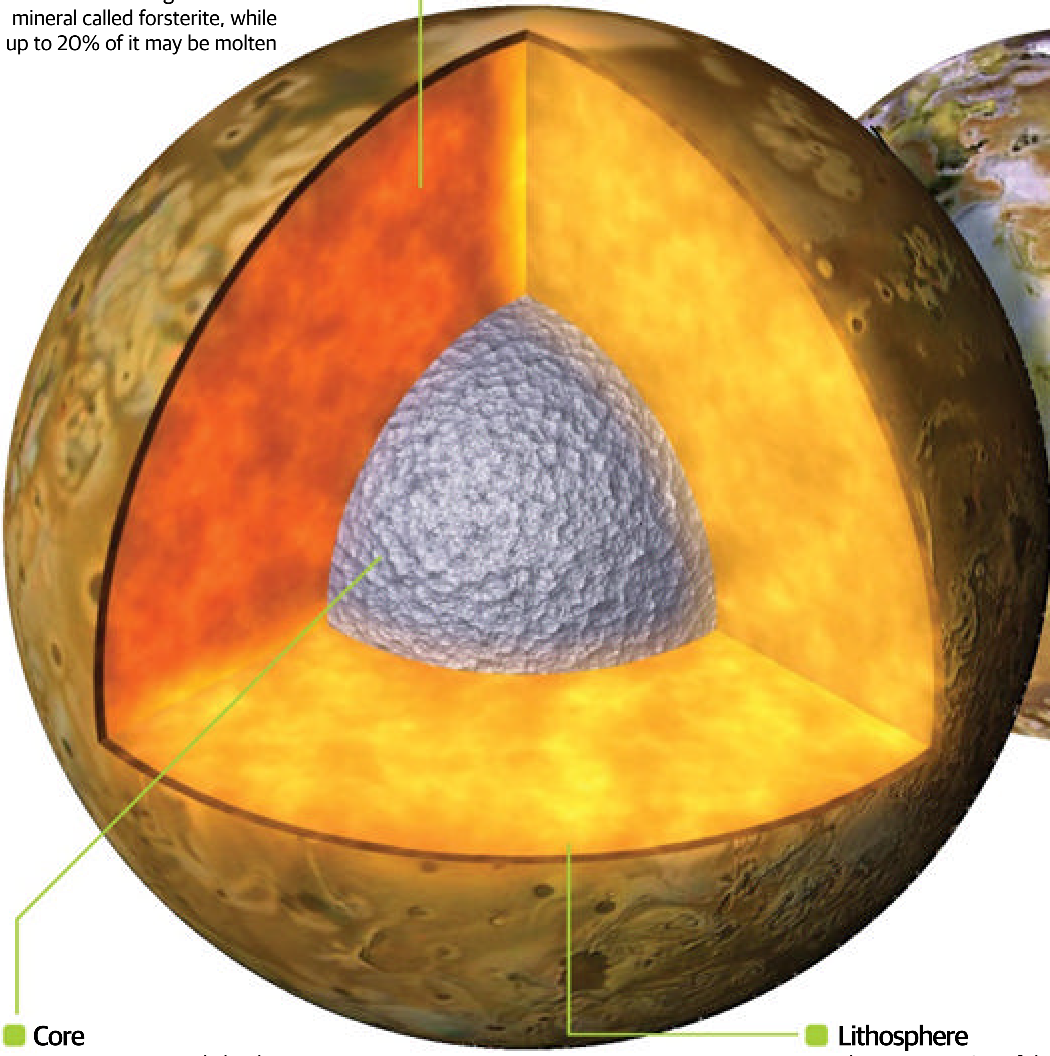
Biggest volcanoes on Io

The strength of volcanoes on Io is measured using the gigawatt, a unit of power equal to a billion watts. For comparison, ten gigawatts is approximately equal to the power the Space Shuttle produced at lift-off

>10,000 GW (gigawatts) · 1,001-10,000 GW · 101-1,000 GW · 11-100 GW · 1-10 GW



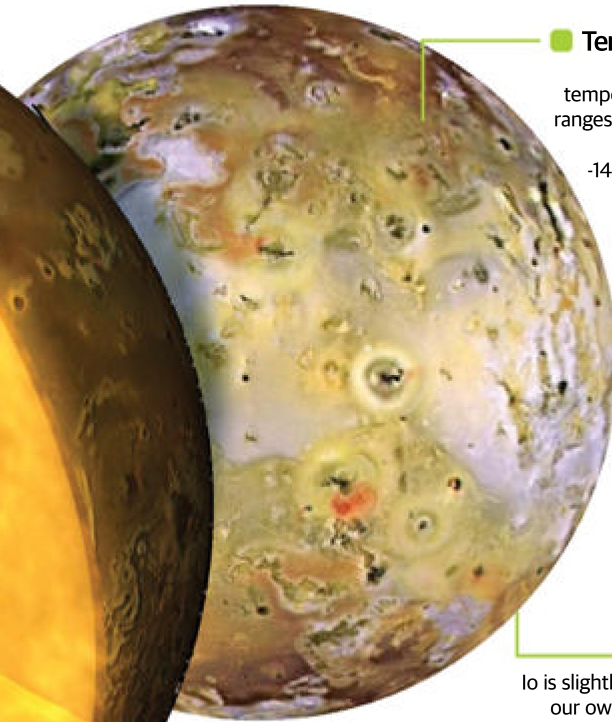
Alien volcanoes on Io



Mantle
The mantle of Io is thought to be made of a magnesium-rich mineral called forsterite, while up to 20% of it may be molten

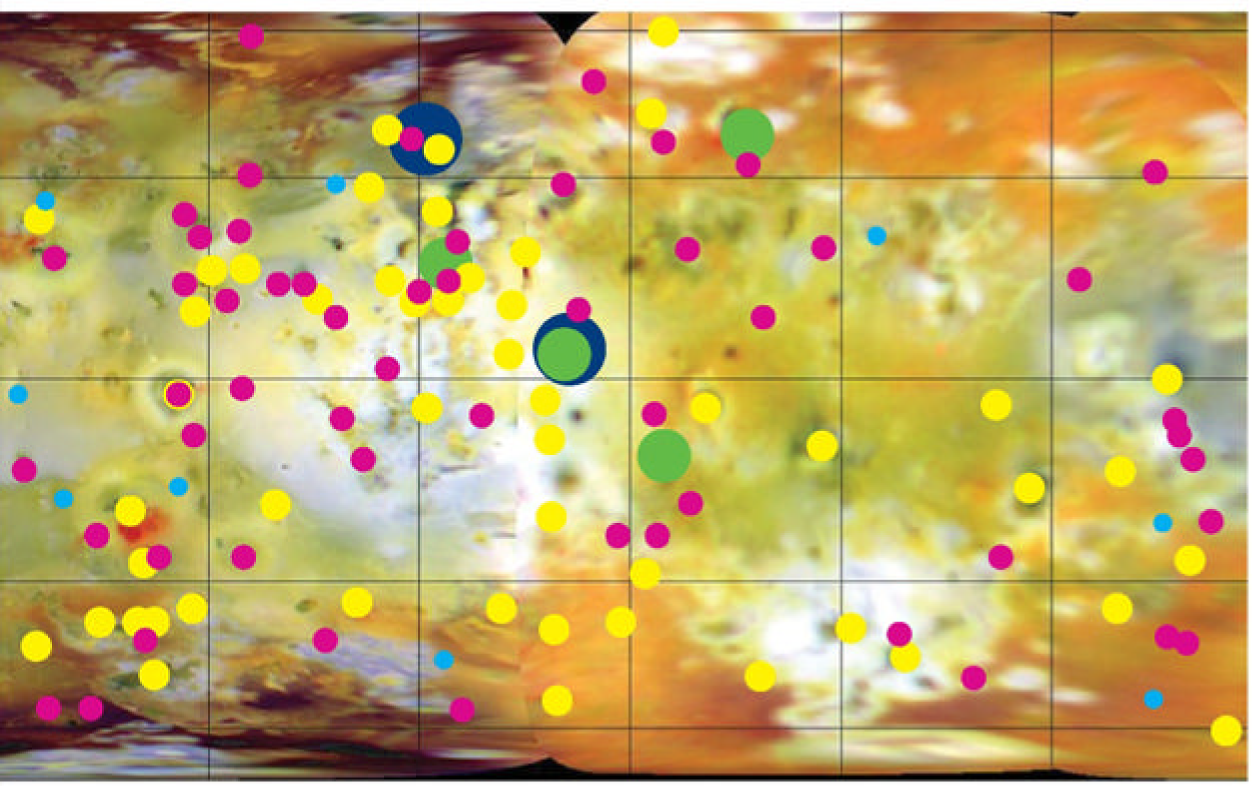
Core
Measurements made by the Voyager and Galileo spacecraft suggest that at Io's centre is an iron-rich core

Lithosphere
The upper portion of the mantle, the lithosphere, is made of basalt and sulphur deposited from the various volcanoes on Io



Temperature
The surface temperature on Io ranges from -180°C (-290°F) to -140°C (-220°F)

Size
Io is slightly larger than our own Moon with a diameter of about 3,600km (2,240 miles)



Io's other amazing features

Freezing cold
One of the most astounding things about Io is that, despite the number of active volcanoes on its surface, it has a maximum surface temperature of -140°C (-220°F). This is because Io's atmosphere is incredibly thin, with volcanic gases instantly freezing and condensing upon eruption rather than adding to the atmosphere like on Earth.

Lightning storms
Io's orbit sees it cut across Jupiter's magnetic field lines, turning the moon into a giant electric generator. In fact, Io generates about 400,000 volts across itself, in turn creating 3 million amperes of current. This makes its way back along Jupiter's magnetic field lines and causes lightning storms in its upper atmosphere.

Magnetic field
The magnetic field of Jupiter also has another effect on Io. As it sweeps past the moon it actually strips off about 1,000kg (2,200lb) of material per second, which in turn becomes ionised and forms a ring-shaped cloud of radiation. The ions in this ring create auroras at the planet's poles, and also inflate Jupiter's magnetosphere to twice its expected size.

Sights of the Universe

From what stars are made of to our relationship with space

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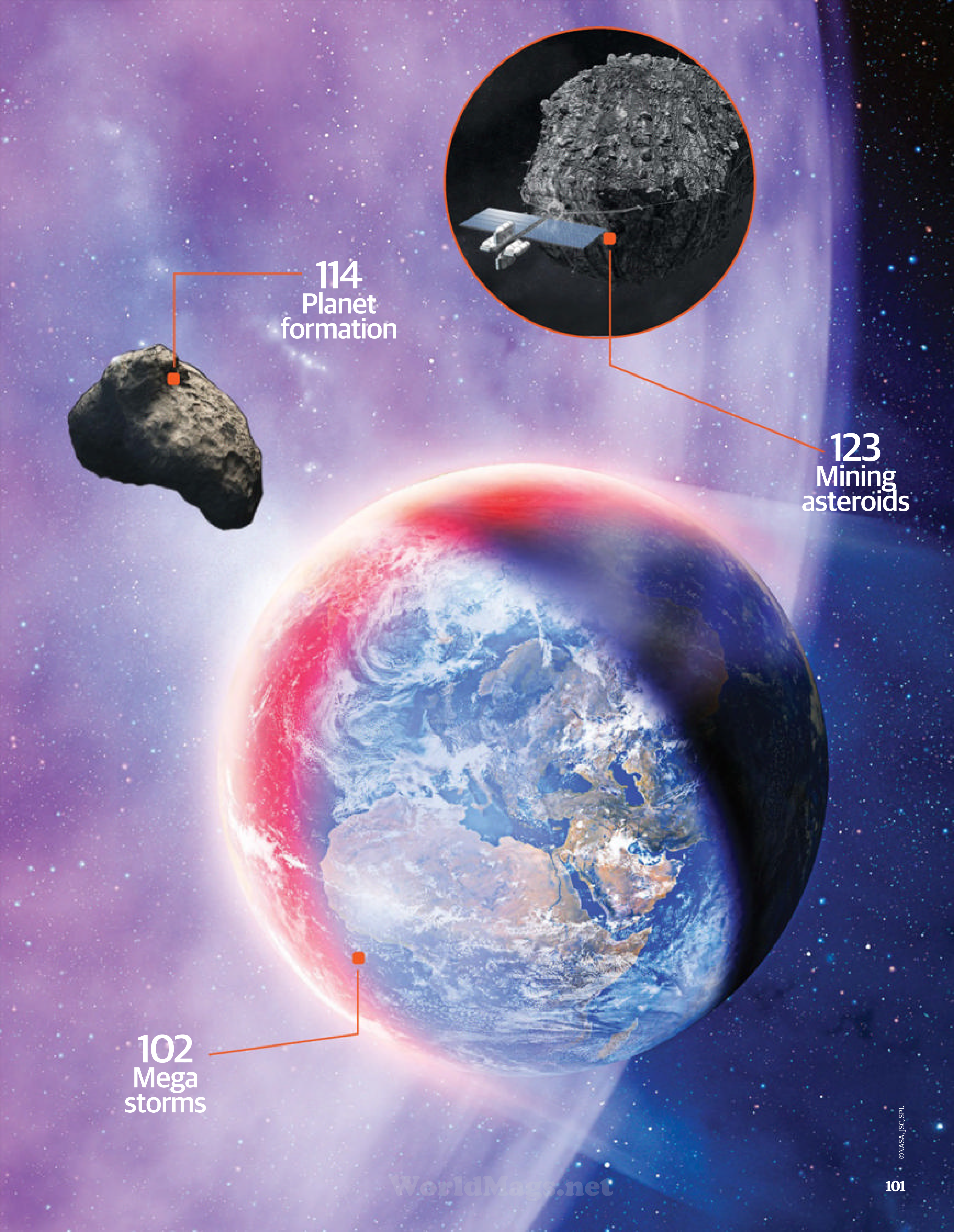
Inside a star

120
Asteroid make-up



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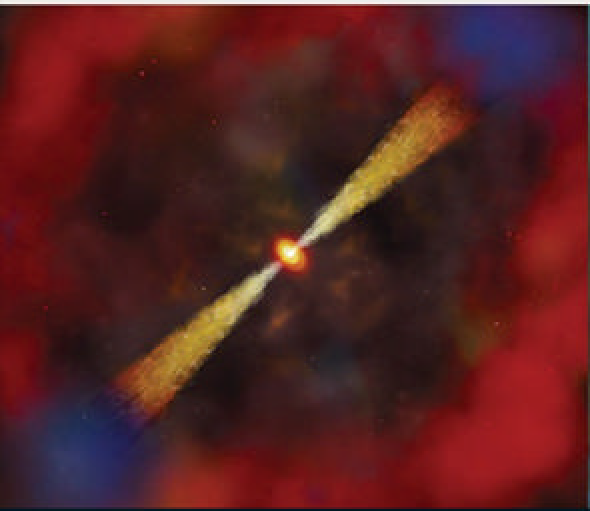
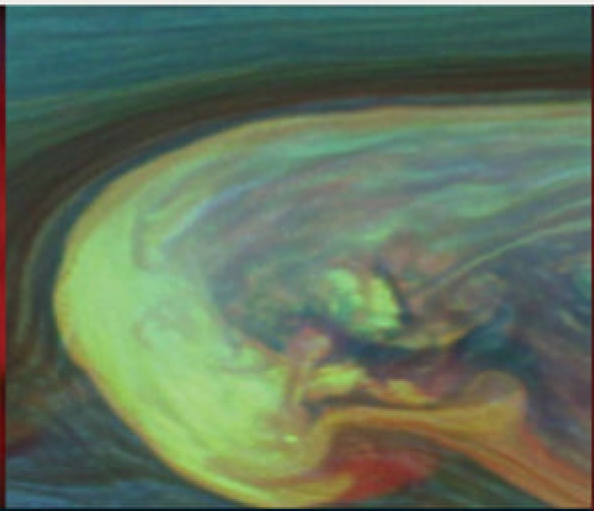
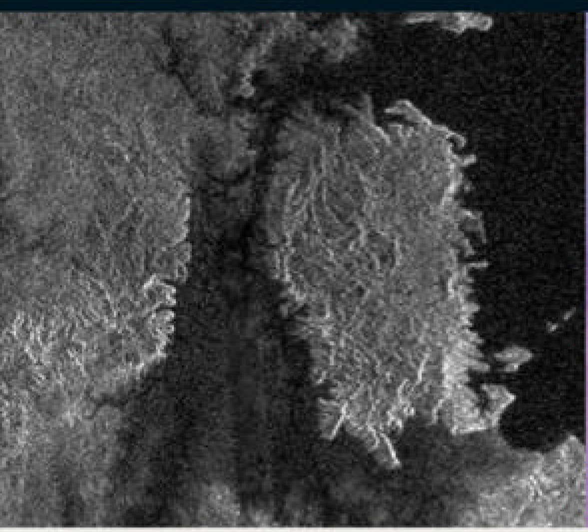




DEADLY WEATHER IN SPACE MEGA STORMS

From solar flares that knock out satellites to 1,500mph hurricanes on the surface of alien worlds, we explore some of the most extreme weather in the Solar System



Our angry, stormy Sun

We know our Sun as a brilliantly bright sphere that rises in the east and sets in the west each day. That's a simple way to describe it; what really goes on on its surface is far from the impression that it gives as it hangs, almost calmly, in the daytime sky.

While going anywhere near the Sun would be suicide with the searing heat and penetrating radiation combining to fry you alive in your spacesuit, technology has revealed this star to be an angry, bubbling cauldron of solar activity.

First up are solar flares - bursts of radiation from the sudden release of magnetic energy from active regions on the Sun's surface, the photosphere. These regions are centred on sunspots, which are tangled knots of magnetic fields. The flares release as much as a sixth of the total amount of energy that the Sun releases every second, with much of it in X-rays or ultraviolet light. The energy of a flare can drive a cloud of charged particles to escape the solar corona in a coronal mass ejection (CME). The CME becomes a giant cloud of plasma hurtling through space and, when CMEs are pointed towards Earth, they cause solar storms.

When a CME strikes the Earth's magnetosphere, it overloads the system and becomes a geomagnetic storm. Earth's magnetosphere is compressed to breaking point with charged particles flooding the magnetic field lines that loop down on to the magnetic poles of the planet. The particles excite atmospheric gases (mainly oxygen and nitrogen), causing them to glow in eerie shimmering curtains of light – the aurora borealis (northern lights) and the aurora australis (southern lights). Oxygen gas glows green, while nitrogen glows purplish-red - the two primary colours seen in auroras. Usually low-level solar wind activity means that the 'auroral arc' is kept, in the northern hemisphere, to the Arctic Circle but the power of a geomagnetic storm can see the auroral arc extend to more southerly latitudes, over Britain and Western Europe, as far south as Spain or even, on very rare occasions, Florida in the United States. The most severe solar storm on record was the Carrington event of 1859, when auroras lit up the skies as far south as the tropics and telegraph wires began to short, sparking electricity.

Those telegraph wires remind us that auroras are only the pretty side of a geomagnetic storm. Although they are not directly harmful to people on the ground, a storm instigated by a powerful CME can destroy our technology. Satellites can short-circuit, knocking out communications. Astronauts must take shelter from the radiation in a special, shielded room onboard the International Space Station. On the ground, power lines can become swamped by raw current from the CME plasma - in 1989, a solar storm caused a large, nine-hour blackout in Quebec in Canada. In our modern world, where we rely on electronic devices, the nightmare scenario is that a powerful enough solar storm could stop everything working, wiping computers, crashing the internet, knocking out global

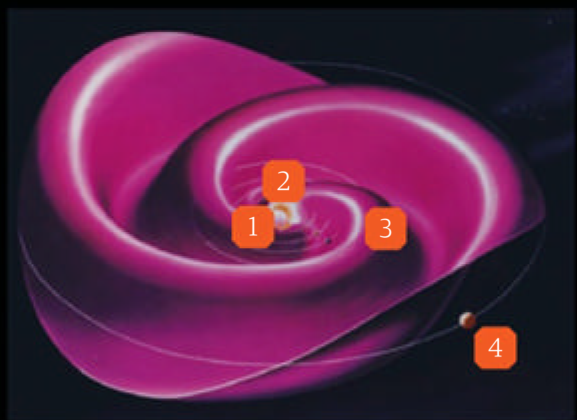
Solar wind current

1. Surface of the Sun
The Sun's magnetic field is very complex on the solar surface, but as it rises into the corona it simplifies until it consists of two opposite polarities separated by the line of the heliospheric current sheet.

2. Corona
In the corona the solar wind begins to draw out the heliospheric current sheet into space, extending the Sun's atmosphere out into the rest of the Solar System.

3. Rotation
As the Sun rotates, it causes the heliospheric current sheet to become twisted.

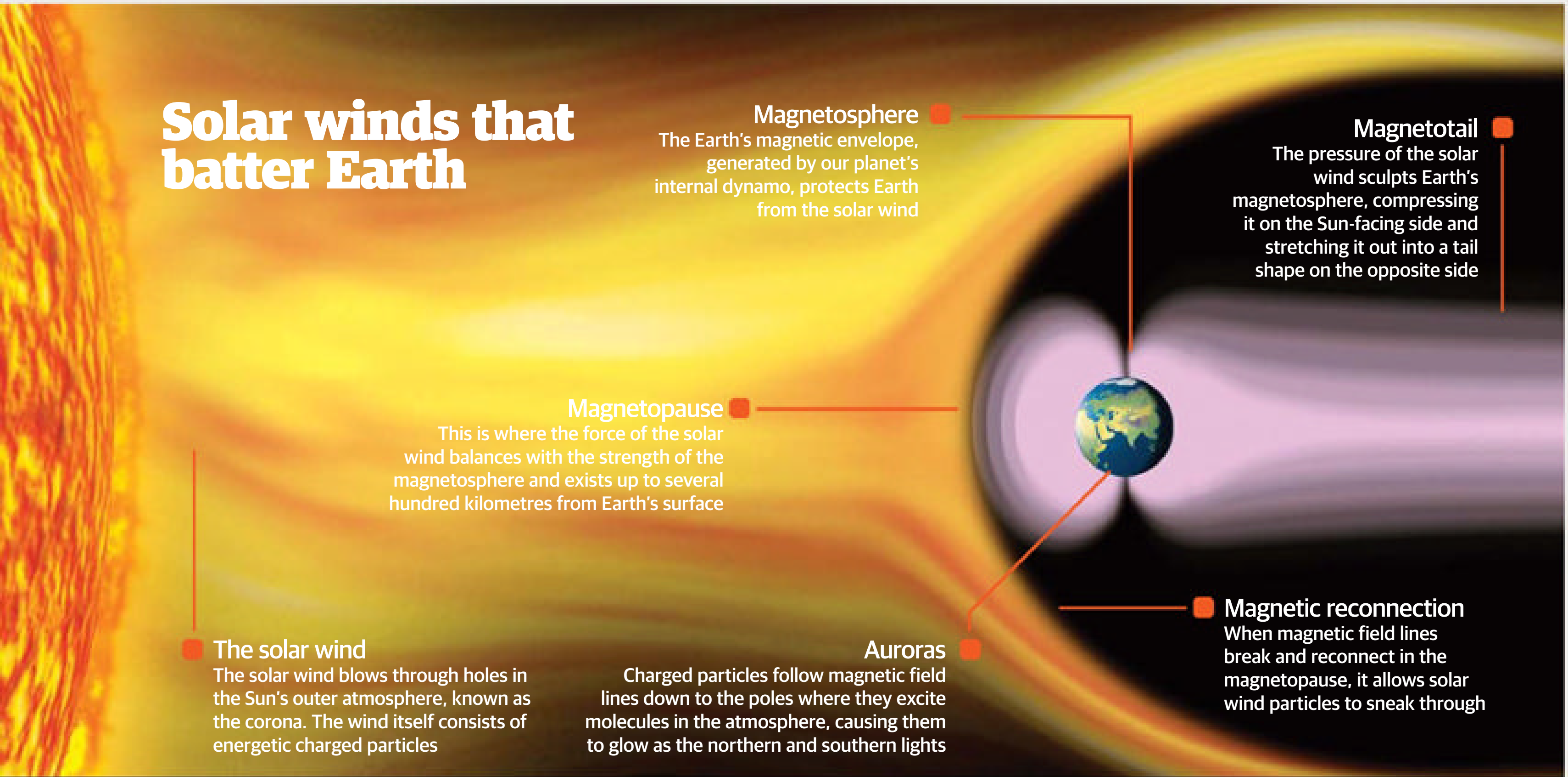
4. Jupiter
It takes material in the heliospheric current sheet three weeks to reach Jupiter. The sheet eventually extends out into the Kuiper belt, where the Voyager spacecraft are exploring.



A solar prominence is an eruption of hydrogen gas from the Sun's surface

WHERE DOES THIS HAPPEN?

Solar winds that batter Earth



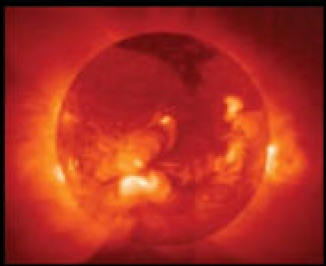
"A powerful enough solar storm could wipe computers, crash the internet and knock out global power systems"

power systems and disrupting communications. It may take months to get everything back online, in which time the world has been sent into technological, social and economic chaos.

We're most vulnerable to solar storms at solar maximum, which is the point in the Sun's 11-year cycle of activity when our nearest star is at its most active. Solar flares happen all the time, and CMEs strike Earth frequently, but only rarely are they as powerful as the solar activity that plunged Quebec into darkness. However, scientists are currently unable to predict solar activity or when the next big CME will be.

All of this takes place in the Sun's heliosphere, which is the extent of its magnetic influence throughout the Solar System, where the solar wind still blows. The heliosphere goes out past the orbit of Pluto. The Voyager 1 spacecraft is currently 118 times further from the Sun than Earth is, and yet it has still to leave the heliosphere. CMEs disperse and lose power the deeper they get into the Solar System. However, solar activity can still have an effect, even on the edge of the heliosphere. Both Voyager 1 and 2 have experienced the heliosphere swelling and shrinking on gusts of the solar wind that inflate the Solar System's magnetic bubble.

The aurora borealis (northern lights) and aurora australis (southern lights) can be seen in the northern and southern hemispheres of our planet



The solar maximum

Roughly every 11 years, the Sun goes through a natural cycle marked by an increase or decrease in dark blemishes on the Sun's surface, or photosphere, known as sunspots. We refer to the multiplication of sunspots as the solar maximum and the smaller number the solar minimum.

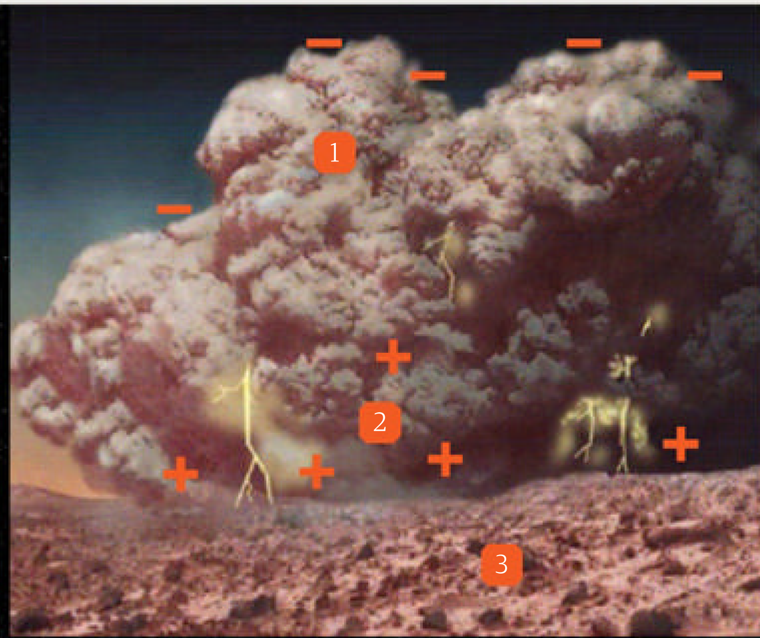
During the solar maximum things get exciting; bright luminous regions also appear in the Sun's atmosphere, called the corona, and it is here where our Sun has an angry outburst; fiercely spitting charged particles and magnetic fields from its surface in a gigantic burst of a supersonic solar wind, called a coronal mass ejection.

Dust storms that cover the planet

Now this is really bad weather – a dust storm that doesn't just cover an area, or even a hemisphere, but the entire planet. During summer in the Red Planet's southern hemisphere, when Mars is at its closest point to the Sun, solar heating can drive immense storms that blow up red dust and can obscure the surface for months. In 1971, when Mariner 9 arrived at Mars, it found the whole planet hidden under a veil of dust, with only the volcano Olympus Mons visible. More recently, the Mars Exploration Rovers Spirit and Opportunity would struggle to survive in dust storms as the Sun's light was blocked and their solar panels covered by a coating of dust.

On Earth, moisture arms swirling storms, but on Mars there is only dust. Normally most of the dust is on the ground, but some is found in the atmosphere, where it scatters sunlight and makes the sky appear pinky-red. When Mars is at its hottest – still cold enough to freeze water – the atmospheric dust can absorb the energy of the sunlight, which causes warm pockets of air to rapidly move towards colder, low-pressure regions, generating winds up to 45 metres per second (162 kilometres per hour or 100 miles per hour) that begin to pick up dust particles from the ground, adding to the atmospheric dust content and increasing heating, pushing the winds harder and faster until the atmosphere is filled by dust.

And then, just as quickly, the storm can die down. Perhaps by blocking the sunlight, the surface of Mars grows cooler, allowing some of the dust to begin sinking out of the atmosphere. Not all dust storms swallow the entire planet – some are more localised events. However, were you to be on the surface during a dust storm, other than the sky darkening and a fine coating of dust settling over you, the atmosphere is so thin that you'd barely notice the wind or the scouring dust.



Kicking up dust

1. Desert dust

The dust storms, that frequently rise from the cold deserts of Mars, sometimes rage across the entire Martian globe, which crackle and snap with electricity.

2. Electrifying dust

It is possible that dust particles could be electrified in Martian dust storms when they rub against each other as they are carried by the winds, transferring positive (+) and negative (-) electric charges similar to the way that static electricity can be built up from shuffling across a carpet.

3. Strong swirls

Electric fields generated by the swirling dust are thought to be strong enough to break apart carbon dioxide and water molecules in the Martian atmosphere recombining to make reactive chemicals like hydrogen peroxide, which you'll find in bleach or other cleaning agents, and ozone. Some of these reactive chemicals are likely to have accumulated in the Martian soil over time.

Snaking its way across Mars's surface, this dust devil is powered by solar heating just like the dust plumes found on Earth

How do dust storms form?

1. Heating up the atmosphere

The absence of clouds or water means that radiation cannot be reflected back into space and the thin atmosphere close to Mars's surface becomes hotter than the atmosphere above it

2. Picking up the dust

As the atmosphere is heated dust is lifted into the air and, after absorbing more sunlight, the dust warms up the atmosphere further, propelling more dust into the air

3. The storm begins

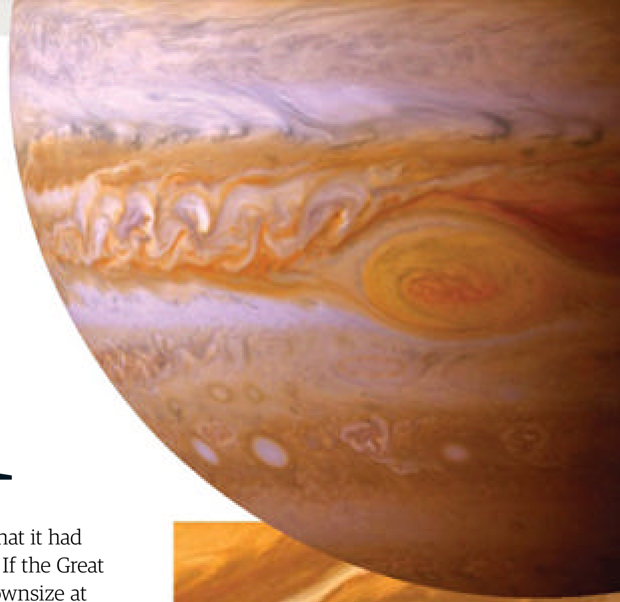
The change in temperature creates winds, swirling at great speeds of 96 to 193km/h (60 to 120mph), capable of dominating the entire planet

4. Dusty dirt devils

As well as the gigantic dust storms, Mars's surface is also raked with frequent, and strong, dust devils

WHERE DOES THIS HAPPEN?

SUN
MERCURY
VENUS
EARTH
MARS
JUPITER
SATURN
URANUS
NEPTUNE
BEYOND SOLAR SYSTEM



Hurricanes bigger than Earth

Easily one of the most famous storms in the Solar System, Jupiter's Great Red Spot is so large that it is visible through many Earth-based telescopes.

The Great Red Spot is thought to have been in existence for at least 340 years. The oval red eye rotates in an anticlockwise direction due to the crushing high pressure on the planet. Winds can reach over 400 kilometres per hour (250 miles per hour) around the spot, however, inside the storm they seem to be nearly nonexistent. And that's not all, this complicated weather system has an average temperature of about -162 degrees Celsius (-260 degrees Fahrenheit).

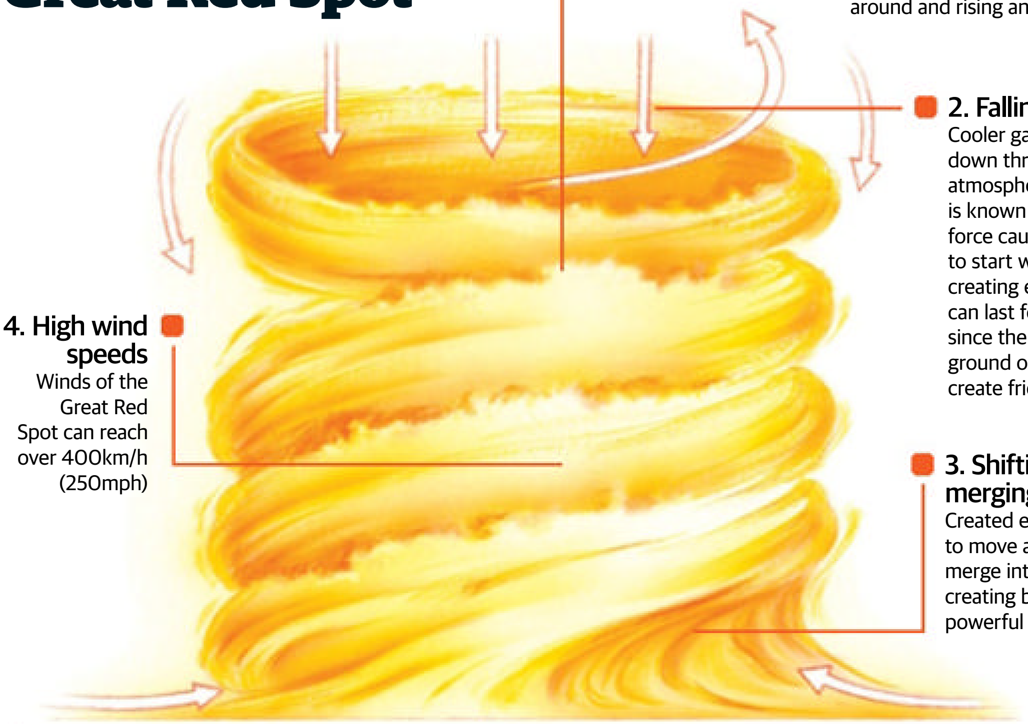
At around eight kilometres (five miles) above the surrounding clouds and held in place by an eastward jet stream to its south and a very strong westward jet flowing into its north, the Great Red Spot has travelled several times around Jupiter, but how did such a behemoth of a storm come to appear on the gas giant's surface?

The answer is not clear at this time despite the efforts of planetary scientists attempting to unravel the answers. However, what experts do theorise is that the storm is driven by an internal heat source, and it absorbs smaller storms that fall into its path, passing over them and swallowing them whole. Another thing that they also know is that the Great Red Spot hasn't always been its current diameter. In 2004, astronomers noticed that the great storm had around half the 40,000-kilometre (25,000-mile) diameter that it had around 100 years before. If the Great Red Spot continues to downsize at this rate, it could eventually morph from an oval shape into a more circular storm by 2040. You might think that this well-known feature won't be sticking around for long as it becomes smaller, but experts believe that the great age-old storm is here to stay since it is strongly powered by numerous other phenomena in the atmosphere around it.

Storms like these are not out of place on Jupiter, whose atmosphere is a zigzag pattern of 12 jet streams, with blemishes of warmer brown and cooler white ovals in the atmosphere owed to storms as young as a few hours or stretching into centuries.

The white oval storm directly below Jupiter's Great Red Spot is about the diameter of Earth

The science of the Great Red Spot



1. A constant twirl
Hot gases in the gas giant's atmosphere are constantly swirling around and rising and falling

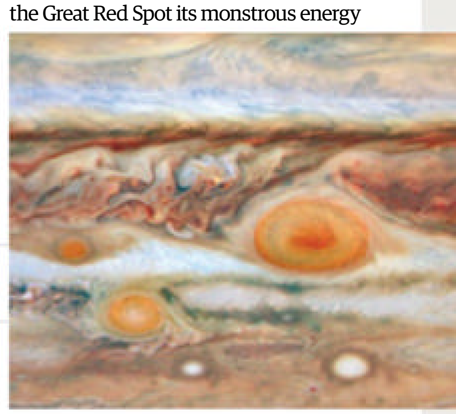
2. Falling cool gas
Cooler gas falls down through the atmosphere, and what is known as a Coriolis force causes the area to start whirling, creating eddies that can last for a long time since there is no solid ground on Jupiter to create friction

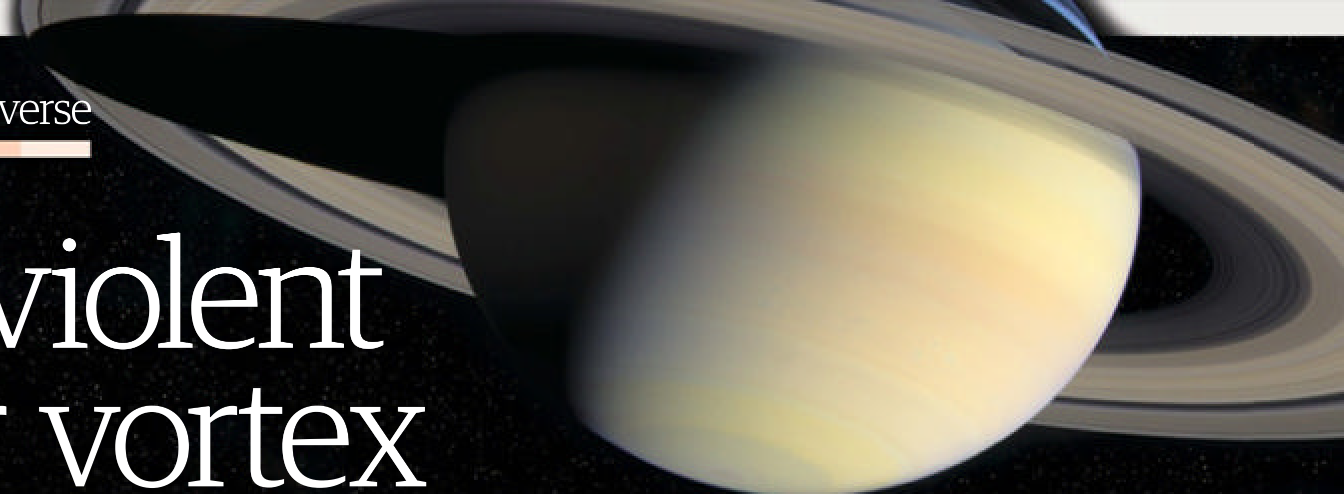
3. Shifting and merging eddies
Created eddies are able to move around and merge into one another, creating bigger and more powerful storms

4. High wind speeds
Winds of the Great Red Spot can reach over 400km/h (250mph)

It is thought that, between Jupiter's core and the cloud tops lies an ocean of liquid hydrogen

Interactions with other storms could give the Great Red Spot its monstrous energy





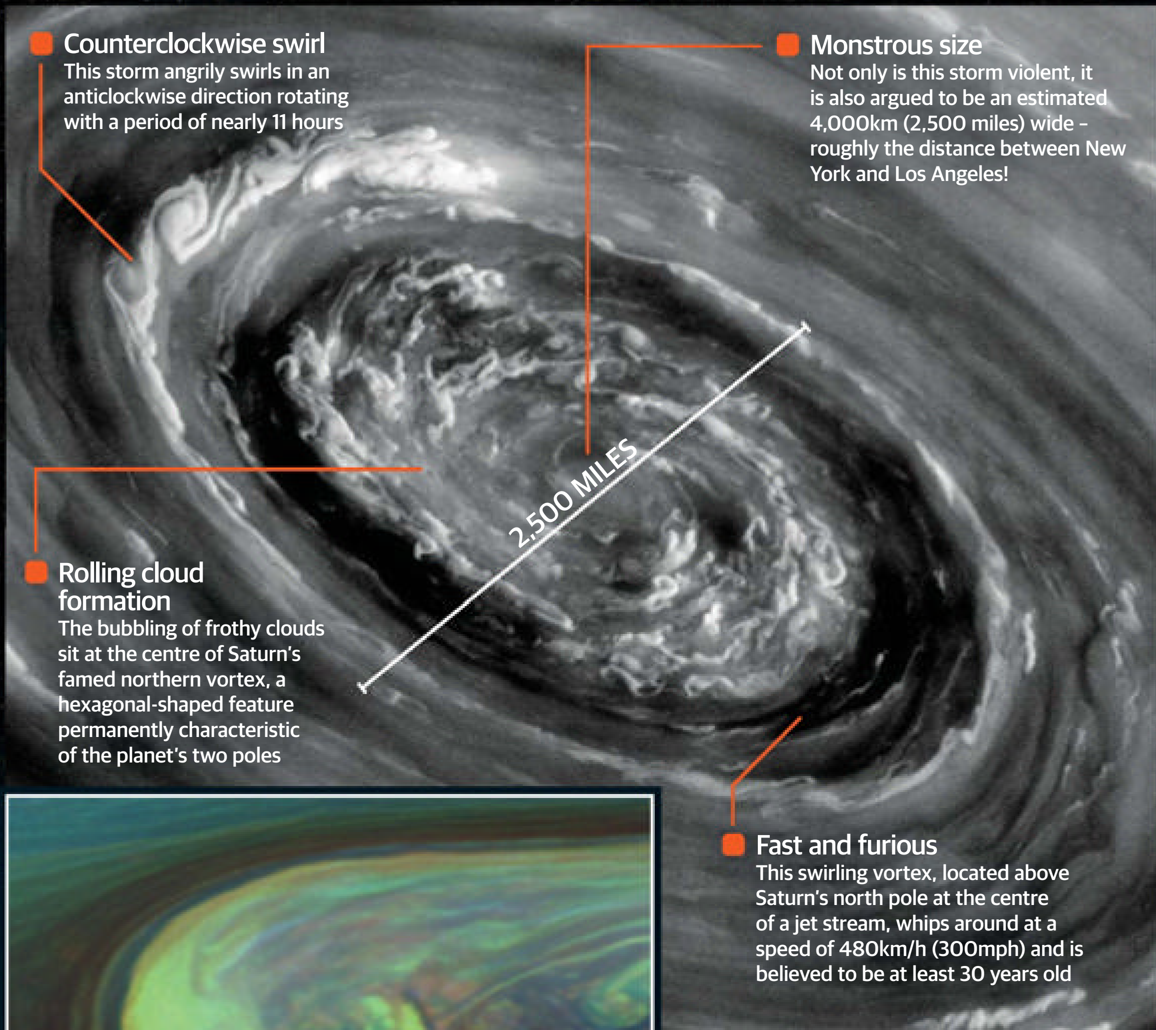
The violent polar vortex

On the outside, Saturn almost looks like a calm, bland world, but once in a while, huge storms flare up on the ringed planet. From the short-lived Great White Spot of 1990, to the more recent storm of 2010, which grew into an atmospheric belt covering around 4 billion square kilometres (1.5 billion square miles), Saturn has proven to be a turbulent world. And what's more, the storms on Saturn are the second fastest in the Solar System, after ice giant Neptune, peaking at an impressive 1,800 kilometres per hour (1,120 miles per hour) and blowing in an easterly direction.

Temperatures on Saturn are normally around -185 degrees Celsius (-300 degrees Fahrenheit), but near the giant swirling polar vortex – a persistent cyclone taking pride of place at the ringed planet's south pole – temperatures start to warm up, and while the climate doesn't reach high enough for a suntan, this -122 degrees Celsius (-188 degrees Fahrenheit) vortex is the warmest spot on Saturn, with a powerful jet stream smashing its way through this terrifyingly fierce feature.

Saturn's north pole also has a giant storm of its own surrounded by a persistent hexagonal cloud pattern. Spotted in 1980 and 1981 during the Voyager 1 and Voyager 2 flybys, Saturn's hexagon, complete with six clear and fairly straight sides, is estimated to have a diameter wider than two Earths. The entire structure rotates almost every 11 hours.

Sighted much more closely by NASA's Cassini spacecraft in 2009 as springtime fell on the ringed giant's northern hemisphere, experts believe that the storm could have been raging for at least 30 years, whipping around at over 480 kilometres per hour (300 miles per hour) in a counterclockwise direction and disturbing frothy white clouds in its wake.

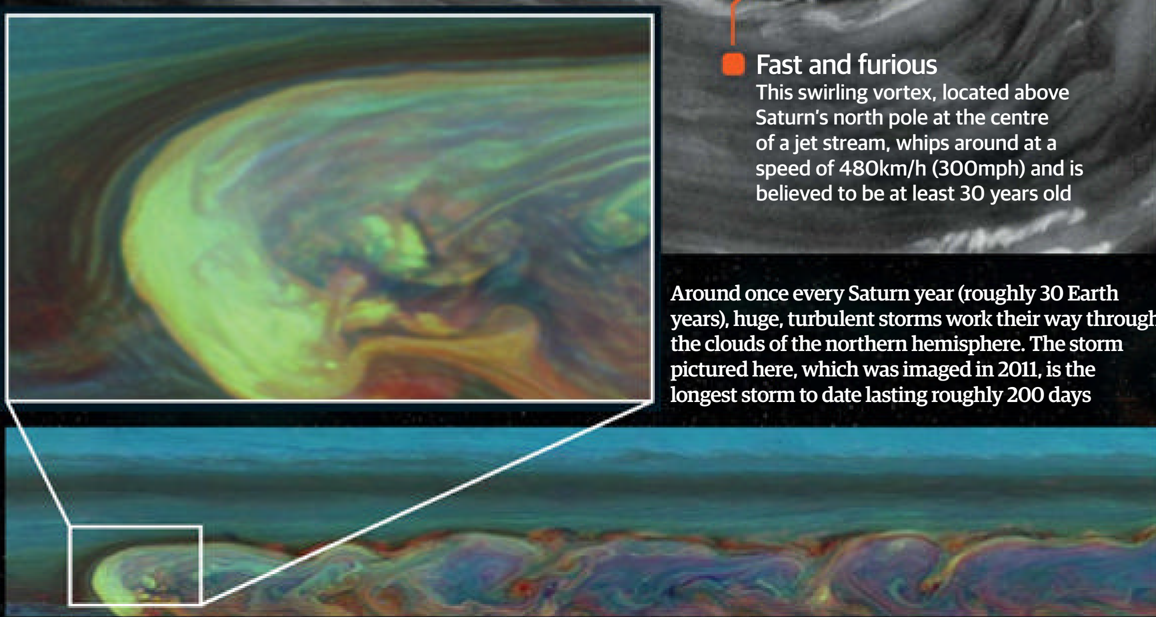


Counterclockwise swirl
This storm angrily swirls in an anticlockwise direction rotating with a period of nearly 11 hours

Monstrous size
Not only is this storm violent, it is also argued to be an estimated 4,000km (2,500 miles) wide – roughly the distance between New York and Los Angeles!

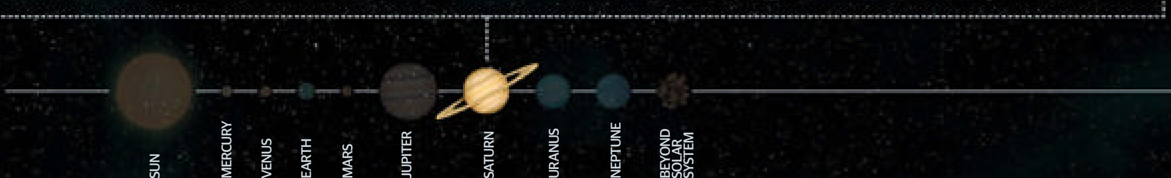
Rolling cloud formation
The bubbling of frothy clouds sit at the centre of Saturn's famed northern vortex, a hexagonal-shaped feature permanently characteristic of the planet's two poles

Fast and furious
This swirling vortex, located above Saturn's north pole at the centre of a jet stream, whips around at a speed of 480km/h (300mph) and is believed to be at least 30 years old



Around once every Saturn year (roughly 30 Earth years), huge, turbulent storms work their way through the clouds of the northern hemisphere. The storm pictured here, which was imaged in 2011, is the longest storm to date lasting roughly 200 days

WHERE DOES THIS HAPPEN?



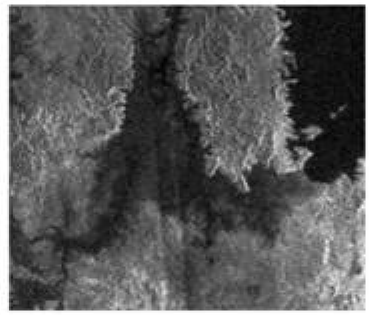
Deadly methane rain

With a surface pressure almost one and a half times that of Earth's, Titan's atmosphere is slightly more massive than our planet's overall, taking on an almost chokingly opaque haze of orange layers that block out any light that tries to penetrate the Saturnian moon's thick cover.

Titan is the only other world, other than Earth, where liquid rains on a solid surface. However, rather than the water that we are used to falling from the skies above us, pooling into puddles and flowing as streams and rivers, this moon's rains fall as liquid methane – liquid hydrocarbons that add more fluid to the many lakes and oceans that already cover the surface. And it is thanks to the moon's complex methane cycle, similar to the natural processes found on Earth, that this is possible.

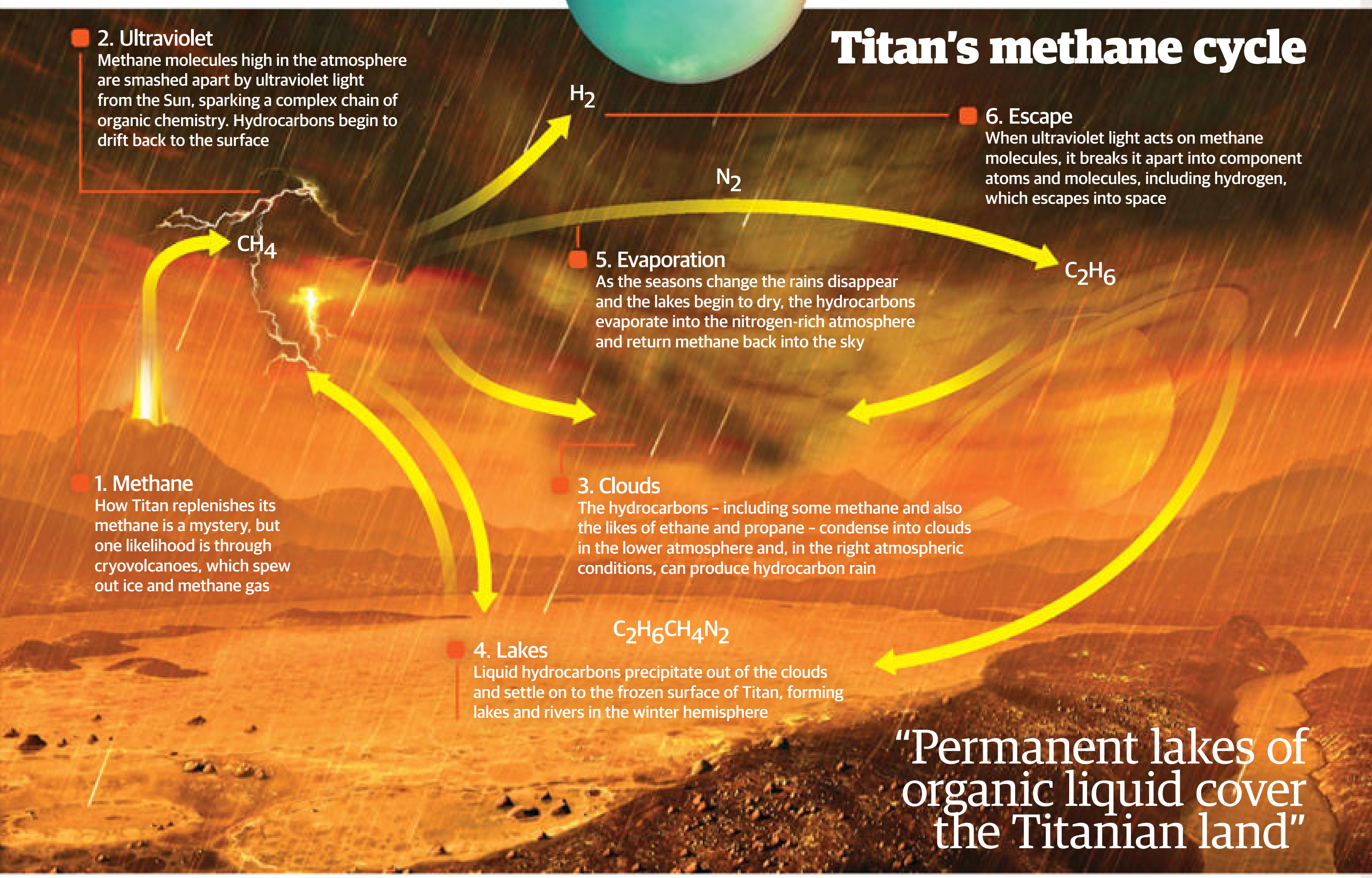
Rain falls quite frequently on Earth, however, the same can't be said for some regions on Titan. Springtime brings rain clouds and showers to Titan's desert with the moon only experiencing rainfall around once every 1,000 years on its arid equator. However, these rain showers certainly make up for the lack of activity by dumping tens of centimetres or even metres of methane rain on to the Titanian surface.

At the poles of the moon its a completely different story, however. Methane rain falls much more frequently, replenishing the lakes of organic liquid covering the Titanian land.



Titan's lakes and rivers of liquid hydrocarbon are thought to be fed by methane rains brought about by the moon's complex methane cycle

Titan's methane cycle



2. Ultraviolet
Methane molecules high in the atmosphere are smashed apart by ultraviolet light from the Sun, sparking a complex chain of organic chemistry. Hydrocarbons begin to drift back to the surface

6. Escape
When ultraviolet light acts on methane molecules, it breaks it apart into component atoms and molecules, including hydrogen, which escapes into space

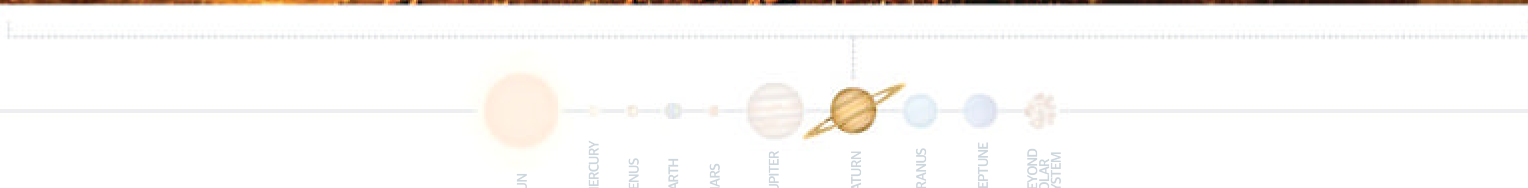
5. Evaporation
As the seasons change the rains disappear and the lakes begin to dry, the hydrocarbons evaporate into the nitrogen-rich atmosphere and return methane back into the sky

1. Methane
How Titan replenishes its methane is a mystery, but one likelihood is through cryovolcanoes, which spew out ice and methane gas

3. Clouds
The hydrocarbons – including some methane and also the likes of ethane and propane – condense into clouds in the lower atmosphere and, in the right atmospheric conditions, can produce hydrocarbon rain

4. Lakes
Liquid hydrocarbons precipitate out of the clouds and settle on to the frozen surface of Titan, forming lakes and rivers in the winter hemisphere

"Permanent lakes of organic liquid cover the Titanian land"



Winds at twice the speed of sound

We've all got stuck out in or witnessed very strong winds here on Earth, from gusts that turn your umbrella inside out to tornadoes that rip up everything in their path. You might think these winds are a force to be reckoned with, but unless you've had a day floating around the gaseous atmosphere of ice giant Neptune you haven't seen anything yet!

You might think that Neptune's distance from the Sun, which creates temperatures as low as -218 degrees Celsius (-360 degrees Fahrenheit), would mean a world frozen solid by the subzero climate with not much going on in terms of weather. However, you would be incorrect. The winds that race through its hydrogen, helium and ammonia-laden atmosphere can reach maximum speeds of around 2,400 kilometres per hour (1,500 miles per hour), making this dark horse probably the most violently stormy world in the Solar System, and making our most powerful winds look like light breezes.

Neptune's fastest storms take the form of dark spots, such as the anticyclonic Great Dark Spot in the planet's southern hemisphere and the Small Dark Spot further south - thought to be vortex structures due to their stable features that can persist for several months - as well as the white cloud group, Scooter.

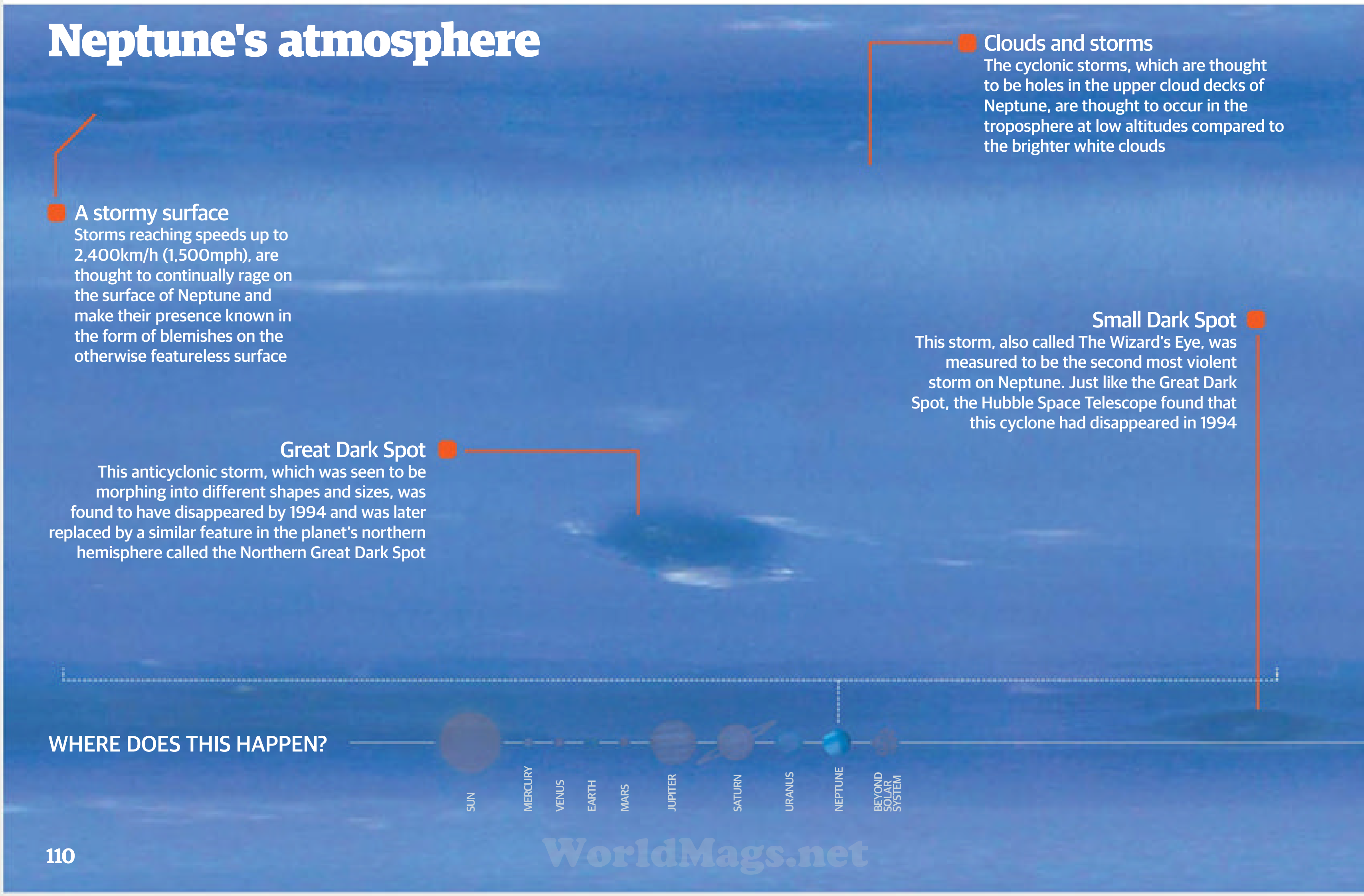
So what causes these winds? Neptune might be extremely frosty, but astronomers think that the freezing temperatures might be responsible; decreasing friction in the gas giant to the point where there's no stopping those super-fast winds once they get going.

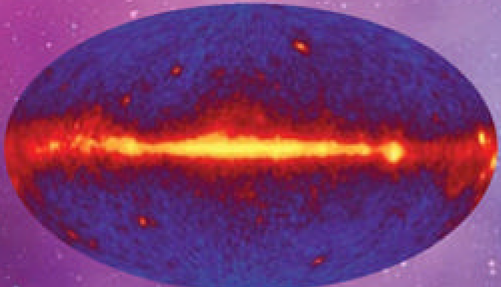
Delving into its layers of gas, we find another possibility pointing to just how these active storms came about as the temperature starts to rise. As things get more snug closer to the centre, the internal energy could be just what is driving the most violent storms that we've ever witnessed.

> "The most violently stormy world in the Solar System"

Long bright clouds on Neptune's surface are similar to cirrus clouds on Earth

The gas giant's atmosphere as imaged by the Voyager 2 spacecraft in 1989





An all sky gamma ray map taken by the Compton Gamma Ray Observatory (CGRO)

Deep space: Lethal gamma rays

While gamma-ray bursts (GRBs) are short-lived, they can pack a punch of energy hundreds of times brighter than your standard supernova

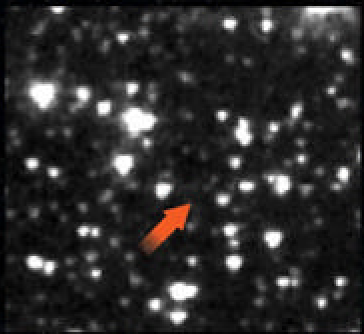
Releasing more energy in a mere ten seconds than the Sun will during its entire 10 billion-year lifetime, gamma-ray bursts reign supreme as the most deadly source of radiation known to man, pipping X-rays to the post.

Taking a trip just outside of the Earth's atmosphere, you'll find that gamma rays are everywhere, however, one of the greatest difficulties in detecting gamma-ray bursts is their incredibly short life span, lasting from just a fraction of a second to over 1,000 seconds. While they can't be seen by our visible light-sensitive eyes, space observatories such as NASA's Fermi Gamma-ray Space Telescope, which is currently performing observations from low Earth orbit, paints a picture of a gamma ray cosmos, proving just how exotic and fascinating our universe is.

But such a high level of radiation doesn't just come out of nowhere, there are many phenomena occurring deep in space, spilling out gamma rays from every pore of the hottest regions of the universe. These hot regions produced in the hearts of solar flares, the explosion of supernovas, neutron stars, black holes and active galaxies, provide these sources.

Back here on Earth we are protected from these bursts of gamma rays by our planet's atmosphere as, unless you're wearing a suit of lead, any interaction with this ionising radiation could prove disastrous as they penetrate through the human body destroying every cell in its path.

But what would happen to life on Earth if we happened to be in the firing line of some intense gamma ray spewing from phenomena such as the nearby explosion of supernovas, an off-the-scale burst from a solar flare destroying the ozone layer, or perhaps the collision between two nearby neutron stars? The answer is not a pleasant one as exposing life as fragile as ours to such a harsh environment would quickly change our currently perfectly balanced world into a deadly orb setting in motion a mass extinction, picking off and destroying life as we know it.



Gamma-ray bursts (GRBs) are gigantic blasts of light whose afterglows fade incredibly fast, lasting anywhere from just a few hours to a few days

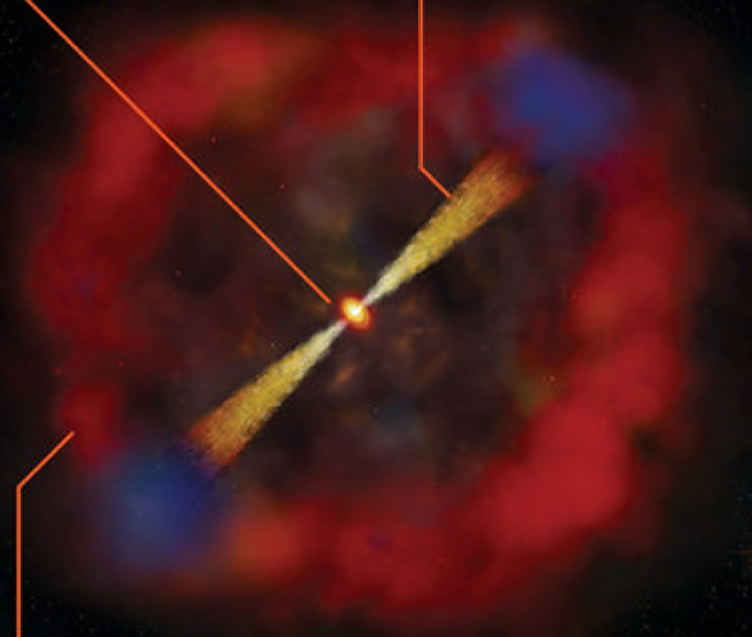
Gamma ray formation

1. Rapidly rotating black hole

The spinning black hole, surrounded by a swirling disc of matter, is thought to be created by the collapse of a massive star's core

2. High energy jets

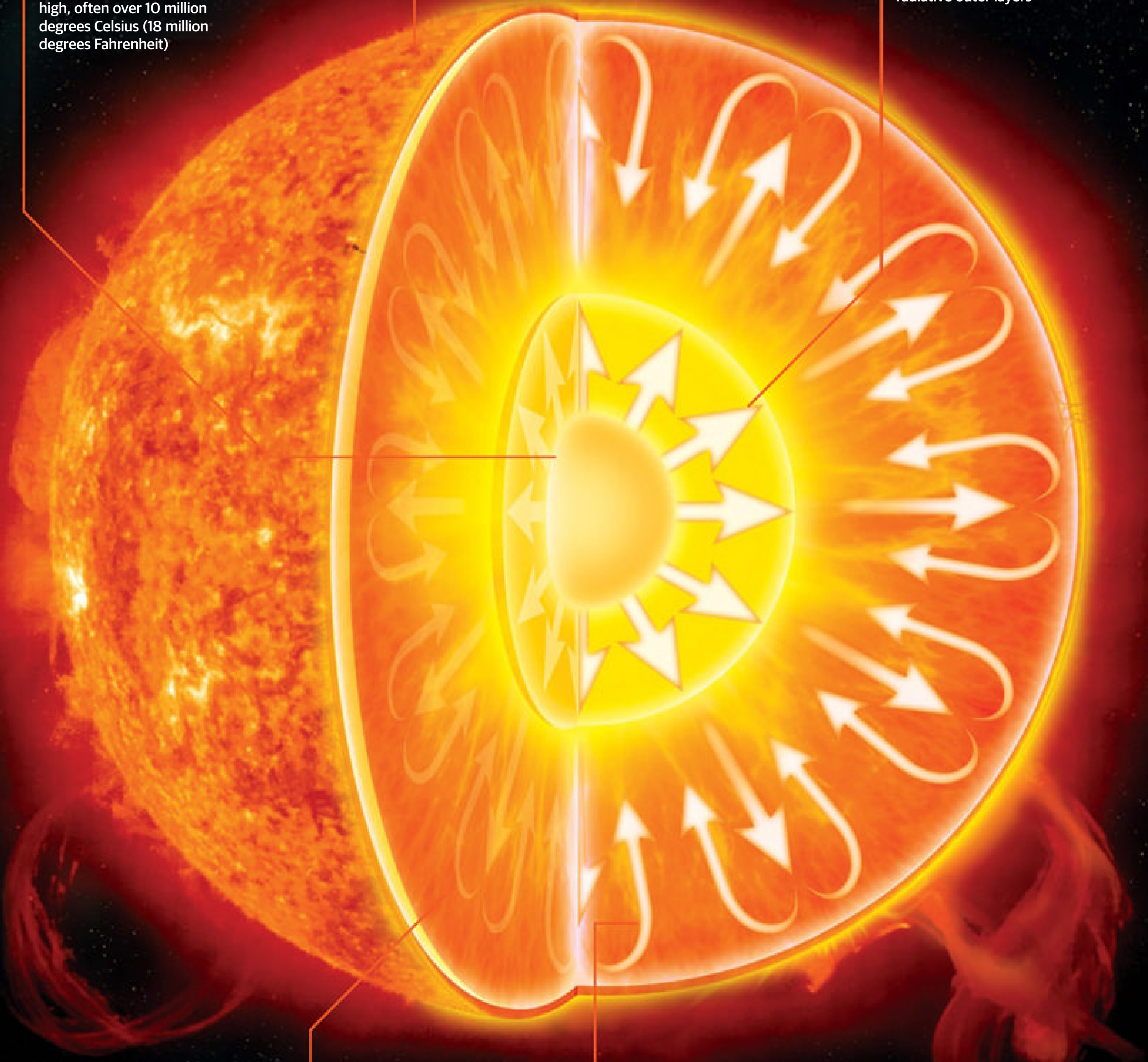
Energetic particles from the rotating black hole shoot out in the form of high energy jets of excited particles



3. Supernova shell

The collapse of the massive star's core causes an explosion that ejects the outer layers of the star at high speeds, producing a shell. The interaction of the jet with this supernova shell produces an X-ray afterglow which can last for days or even months

Anatomy of a star



Core
The core of stars is where the vast majority of their nuclear fusion reactions take place. Temperatures are incredibly high, often over 10 million degrees Celsius (18 million degrees Fahrenheit)

Magnetic field
Magnetic fields permeate all stars, with magnetic field lines arranged according to local conditions. Earth's Sun has a dipole magnetic field. These fields are commonly distorted by the star's internal dynamo

Radiative zone
Each star has a radiative zone where energy from the core is directly radiated outwards through its gaseous material. Low-mass stars have radiative inner layers, while high-mass stars have radiative outer layers

Subsurface flows
Subsurface flows are driven by both the distorting effect of the star's dynamo and also, on low-mass stars, by large convection zones that unstably transfer energy to the near surface in circular motions

Convection zone
Driven by the fluid motion within the star's shells, convection zones are the secondary energy transportation process within stars. They only occur when radiative heat transfer is ineffectual, due to a high opacity of shell material

What happens inside a star?

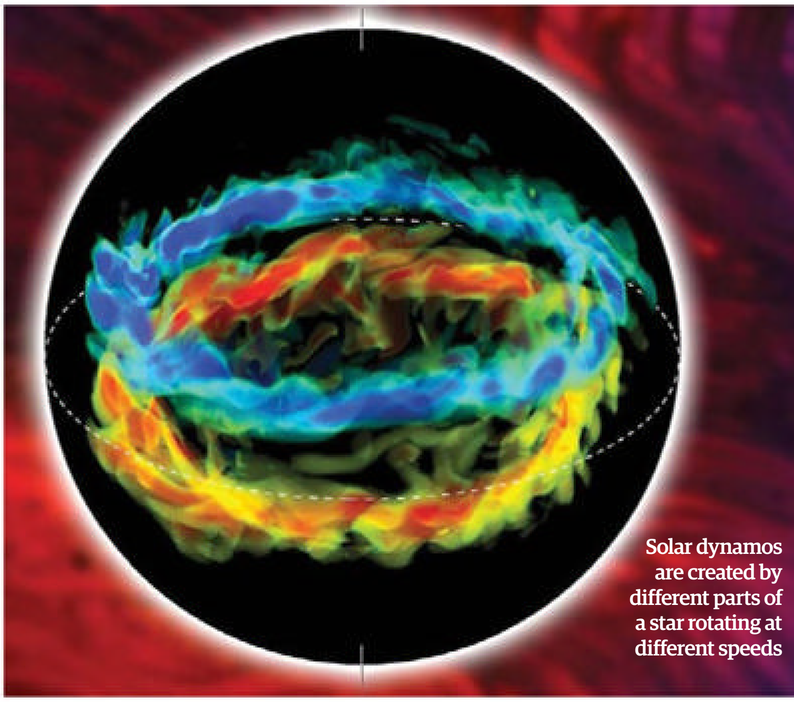
While the surface of a star - known as its photosphere – appears a busy place, it is nothing compared to its interior, which is a hive of physical processes

First, there is the process of hydrostatic equilibrium, which largely determines the star's density structure and is a counteracting sequence where the star's internal pressure gradient pushes against and counteracts the force of gravity. In essence, this determines the stability of the star's shell structure, its various rings of material (such as plasma) and forces emanating from the core. Without this stability, the various shells of the star will either contract or expand. For a star like our Solar System's Sun, the hydrostatic balance is finely tuned, as the star has been stable for over 7 billion years. However, for a star such as red supergiant Betelgeuse, it is not, hence the uneven shell structure.

The second key physical process within stars is energy transportation, which is important as the temperature of its gas determines the density structure via its hydrostatic equilibrium. The transportation of energy within stars can happen via two processes, either by radiation or convection. In main sequence stars - such as our Sun - these processes are typically localised in radius to specific zones, with their position determined by the star's mass and shell opacity. Stars with masses over seven times that of the Sun are convective in their inner layers, while radiative in their outer ones due to their high internal mass. In contrast, stars with low mass, tend to be radiative in their inner layers but convective in the outer layers as their opacity is lessened due to their lower internal mass.

Finally, the third key process within stars is nuclear fusion, a series of reactions which occur primarily in the star's core (see the 'Fusion power explained' boxout for more information). These fusion reactions necessitate high temperatures in excess of 10 million degrees Celsius (18 million degrees Fahrenheit) and high densities greater than hundreds of grams per cubic centimetre. Interestingly, the more massive a star is the shorter its life span becomes, as the nuclear fusion in its core occurs at a far quicker rate despite the increased quantity of fusionable material. As such, stars of similar size to our Sun will have a main sequence of approximately 10 billion years, while a star ten times as massive would only last around 20 million years. ●


The AR9906 solar flare


Solar dynamos are created by different parts of a star rotating at different speeds

Stellar dynamos

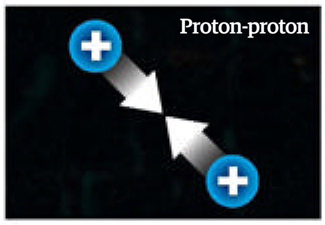
Many stars have a solar dynamo - vast rings of electrically conductive plasma that are charged through a shearing effect between different parts of the star rotating at different speeds. This shear charges the plasma to such an extent that they can warp the magnetic field lines.

This distortion is so severe that the magnetic field lines tend to be dragged along with the fluid in a whipping motion. Indeed, it is because of this distorting effect that many stars demonstrate sunspot cycles, with the star's dynamo extending its field lines so much that they pierce the surface of the photosphere.

Fusion power explained

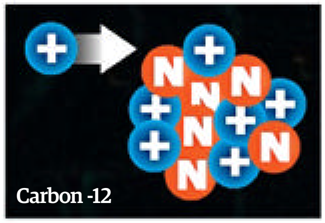
Proton-proton fusion

A nuclear fusion process that fuels stars with core temperatures less than 15 million Kelvin, proton-proton fusion is a common reaction. It entails two protons fusing, with one being transmuted to a neutron, forming deuterium. The deuterium then fuses with another proton, generating a helium nuclei, two of which then fuse to generate an alpha particle and the release of two protons.



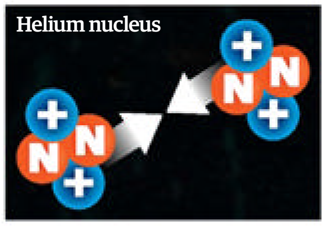
Carbon fusion

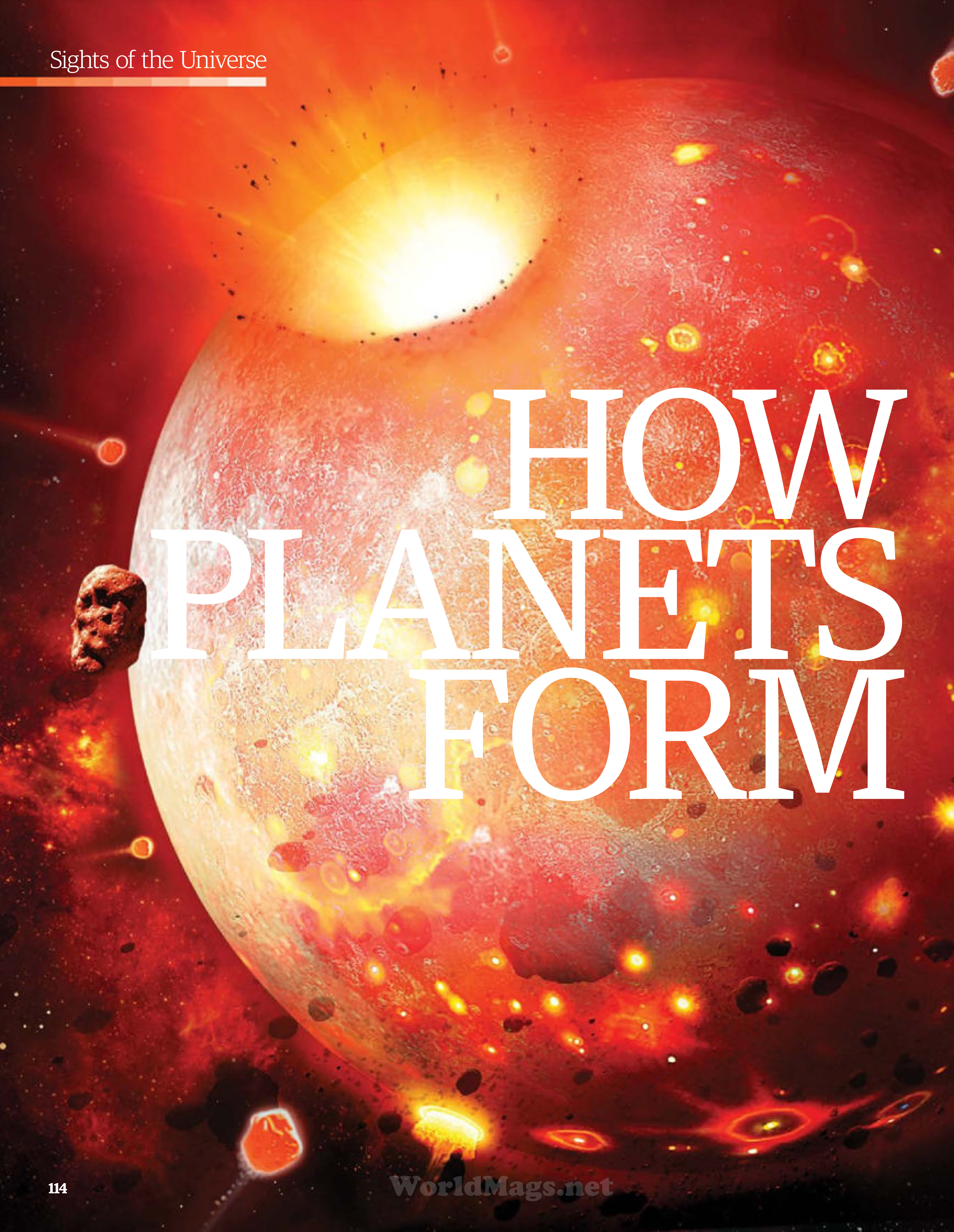
For stars with central temperatures over 15 million Kelvin, carbon fusion tends to be the dominant process. It revolves around adding protons to carbon and then nitrogen over multiple sequences. The end result is the generation of an oxygen-16 atom, which emits an energetic alpha particle. This is not a major part of the Sun's reaction cycle, but is prevalent in the star Sirius.



Helium fusion

If the core temperature of a star exceeds 100 million Kelvin, as is typical of red supergiant stars, then helium-helium can become the dominant reaction. This involves two helium nucleuses fusing to create beryllium-8 and emitting gamma rays, before the beryllium-8 fuses with another helium nucleus and generates carbon-12, which unlike beryllium is stable.





HOW PLANETS FORM

Discover how our home, along with our Solar System neighbours and every other planet in the universe, was born from a chaotic cloud of dust and gas

In a sense, planetary birth is a side effect of a larger birth: the formation of a star. Stars form from nebulas, massive clouds of gas and dust dominated by hydrogen and helium. Now and then, a disturbance in a nebula concentrates an area of gas and dust into a denser knot of material. If the knot is big enough and dense enough, it will exert enough gravitational pull to collapse in on itself. The huge volume of super-dense gas concentrates at the knot's centre, and the gravitational energy heats it up to form a protostar. With sufficient mass, the energy of the protostar increases, eventually initiating a nuclear fusion reaction and graduating to a proper star.

Meanwhile, according to the solar nebula theory, surrounding gas and dust form a protoplanetary disc, or proplyd, around the protostar. When the protostar first begins to form, the surrounding material is still an unordered, slowly churning cloud. But the protostar's growing gravitational pull accelerates the cloud's movement, causing it to swirl around the centre. As the swirling mass speeds up, it flattens out, forming a thin disc, packed with all the material that will eventually coalesce into planets.

As well as explaining how planets form, the solar nebula theory also explains why solar systems take the form they do. The planets all revolve in the same direction around a central star, in the same plane, because that's how the material disc originally swirled around the protostar.

Exactly how it all comes about is still up for debate, and there may actually be many different planet formation processes. The prevailing understanding, called the accretion model, is that planet formation begins when individual bits of matter in the disc clump together into bigger chunks. The accretion model seems to be correct at least in the case of rocky terrestrial planets, like Earth and Mars, which form from silicates and heavier metal, such as iron and nickel.

Astronomers generally agree that a planet like ours begins with an invisible piece of dust. Microscopic grains in the disc grow by condensation, the same process behind snowflake formation. In condensation, individual heavy gas atoms or molecules stick to a grain, rapidly expanding its size into a more substantial solid particle.

When the particles are very small and light, turbulent gas motions stir them up, swirling them outside the flat plane of the proplyd. But when they reach sufficient mass they're heavy enough to settle into the relatively thin rotating disc. In the crowded disc, particles collide more frequently, speeding up the growth of larger and larger chunks.

At about the point a chunk of solid matter grows to a kilometre across, it graduates to a planetesimal. A planetesimal is massive enough that its gravitational pull attracts smaller chunks of matter, accelerating the rate of growth. The result is a relatively small number of planetesimals steadily capturing the smaller chunks and particles in the disc.

When a terrestrial planetesimal grows large enough, the energy of

many collisions along with radioactive material it's accreted heat everything to melting point. As a melted mass, the planetesimal's structure can reform. In a process called differentiation, the force of gravity concentrates the melted metals into an inner core, surrounded by an outer crust of lighter rocky silicates. The result is a protoplanet, an asteroid-like mass with distinct layers. Over time, gravity evens out the protoplanet's shape, forming it into a sphere.

A terrestrial planet might form an atmosphere layer through outgassing. Essentially, heat from the planet's interior core unlocks gases trapped in the planet's solid and molten interior. Planets might then add to this atmosphere through encounters with other solar system bodies.

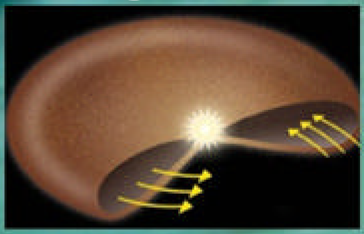
As the diversity of our own Solar System demonstrates, atmospheres vary a great deal. Any particular atmospheric recipe requires not only the right mix of planetary matter, but also a precise balance of planetary size and proximity to the central star. When a smaller planet orbits very close to a star, like Mercury, the Sun's heat blasts away any atmosphere, leaving a barren rock. Meanwhile, a planet like Mars is so far from the Sun that all its water is locked up in ice. But just a bit further in, you get Earth – a planet that's the right size and in the right position to form a robust atmosphere that could support life.

While there is general agreement among astronomers that terrestrial planets formed along these lines, the origins of Jovian gas giant planets, like Jupiter and Saturn, are less certain. One possibility is they start out the same basic way as terrestrial planets, steadily accreting solid matter to form a massive protoplanet. If it grows large enough – about 15 times the size of Earth – such a protoplanet exerts a strong enough gravitational pull to capture hydrogen and helium gas in the proplyd. The gaseous mass then sweeps up more material, growing into a Jovian behemoth.

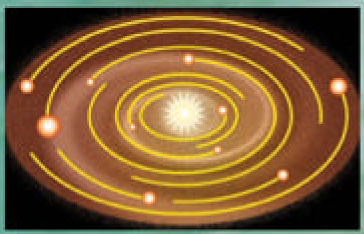
There is a relatively small supply of heavy metals and silicate in a proplyd, making it unlikely that a protoplanet could accumulate enough metal and rocky material to reach the size necessary to hold on to hydrogen and helium gas. Instead, this model says, the initial planetary core of a Jovian planet forms out of frozen hydrogen compounds, such as methane, ammonia and water. Near the centre of a proplyd, the developing protostar makes it too hot for hydrogen

Origins of a solar system

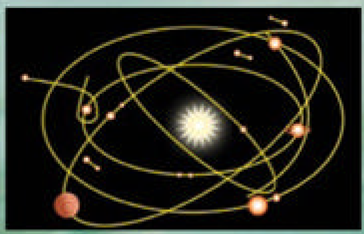
Gas giant, the accretion model



1. Dirty snowballs
Dust grains and bits of frozen hydrogen compounds condense and then collide and stick together, forming bigger and bigger icy planetesimals.

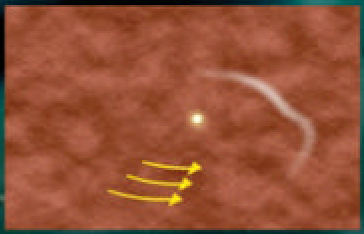


2. Capturing gas
Some planetesimals grow so big that their gravitational pull captures hydrogen and helium gas in the protoplanetary disc.



3. Too big to fail
The gas giants grab a huge supply of the disc's hydrogen and helium gas. Their massive gravity pulls in or scatters remaining planetesimals.

Gas giant, gas collapse model



1. Concentrations in the disc
In the disc of gas and dust that forms around a protostar, the dynamics of the rotation cause uneven distribution of hydrogen and helium gas.

2. 'Instant' planet
A clump of dense gas collapses under its own gravity to form a gaseous planet. The new planet picks up dust and ice, which collect into a solid core.

3. Glutton for gas
As the planet makes its way around the disc, its strong gravitational pull sweeps up more gas, making it bigger and bigger.

A star is born
Astronomers believe a solar system begins when part of a nebula – a molecular cloud of gas and dust – collapses under its own gravity, forming a dense, hot core that becomes a star

Terrestrial planets
Closer to the star, dust particles of heavier metals and minerals like iron and nickel clump together into larger and larger chunks, slowly forming rocky planets

Gas giants
Further away, hydrogen compounds form ice, providing much more planet-forming material. The gravitational pull of much larger planets holds on to hydrogen and helium gas, forming a gas giant like Jupiter or Saturn

The protoplanetary disc
As the star forms, its gravitational pull accelerates and flattens the surrounding molecular cloud, forming a spinning disc of material, which gradually coalesces into planets

A terrestrial world is born

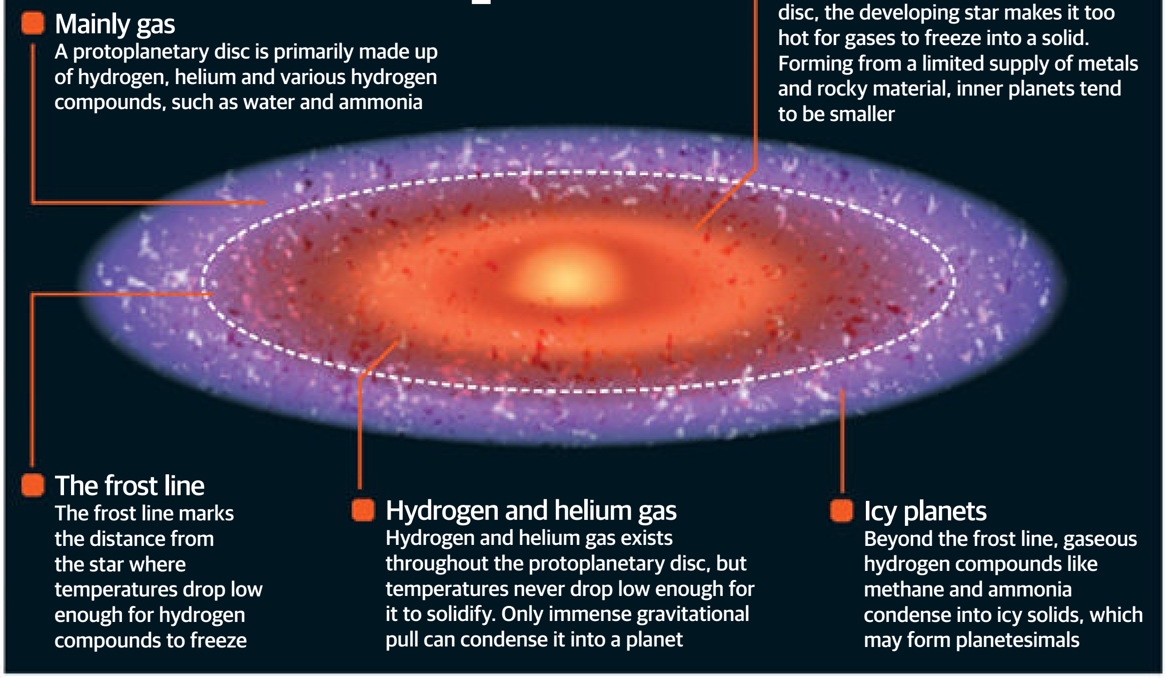
1. Let's stick together
Mineral and metal dust particles throughout the molecular cloud collide and clump together, forming larger rocky particles.

2. Running with the crowd
As trillions of these particles rotate around the developing star, they're constantly colliding, forming bigger asteroid-like pieces through accretion.

3. Forming a planetesimal
When a rocky chunk grows to about 1km across, its gravitational pull is able to attract other pieces, speeding up the accretion process.

4. Graduating to a protoplanet
Intense heat melts the rocky material. During melting, elements like iron and nickel concentrate at the centre of the planet, giving it distinct layers.

The frost line explained



compounds to condense into frozen solids. They remain in gaseous form and so do not accrete to developing planetesimals. But if you move far enough away from the hot protostar, past what's called the frost line, the temperature drops low enough that hydrogen compounds can freeze. With a much more abundant supply of solid material, large icy protoplanets can form and capture the swirling hydrogen and helium gas.

The organisation of our Solar System supports this theory. The inner planets, Mercury, Venus, Earth and Mars are all relatively small and rocky, suggesting forming giant icy or gaseous planets wasn't possible close to the Sun, while the outer planets, Jupiter, Saturn, Uranus and Neptune, are much larger.

The chief argument against the accretion model for Jovian planets is timing. In well-supported models of solar system evolution, there simply isn't enough time to grow the massive icy cores before the developing solar system loses the bulk of its hydrogen and helium gas supply. While the lighter gases are the dominant material during the proplyd's early life, their days are numbered. In the case of our own Solar System, some 10 million years after the Sun first formed as a protostar, the energy of nuclear fusion reactions likely produced powerful solar winds that would have cleared out the remaining gas in the proplyd. That's a tight window for Jovian gas giants to form.

And neighbouring stars may lead to the window shrinking even further. Astronomers believe that stars generally form in clusters that contain massive, hot stars. Calculations say radiation from these stars would accelerate the evaporation of gaseous material in nearby proplyds, shrinking the period of plentiful hydrogen and helium to between 100,000 and 1 million years. That doesn't appear to be enough time for a Jovian gas giant to form through the accretion model, yet observations of distant solar systems show that these gas giants are very common.

An alternative theory, known as the gas collapse model, presents a faster formation scenario. According to this model, gas giants form directly from the swirling hydrogen and helium in a developing proplyd. As the material revolves around the protostar, turbulence in the disc distributes it unevenly. This unevenness forms knots of dense gas. When enough gas is concentrated tightly enough, its dense mass causes it to collapse in on itself, forming a giant gas ball. To put it another way, the gas giant is like a failed star. It forms the same basic way as the protostar, but doesn't have sufficient mass and energy for a nuclear fusion reaction.

The embryonic planet's gravitational pull takes over from there, sweeping up massive amounts of gas, as well as any solids in the vicinity, quickly adding to its bulk. Collected ice and metals condense at the planet's centre, forming a solid core after the gas has accumulated, rather than before. The whole process might happen as quickly as a few hundred years.

Observations of Jovian exoplanets (planets located outside our Solar System) have given some credence to this model - or at least challenged the Jovian accretion model. In the wave of exoplanet discoveries over the past 25 years, one of the biggest surprises has been the so-called 'hot Jupiters', Jovian gas giants that orbit very close to their suns. These planets would seem to contradict the notion that gas giants only form beyond the frost line. However, they may have formed further out, but then migrated towards their suns.

A host of exoplanet discoveries have given astronomers a much bigger picture of the range of possible planets, which has yielded new clues about how planets might form. But examining the end results can only tell them so much. Fortunately, we're likely entering a new era of direct proplyd observation, thanks to advances in telescopic technology. The new Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope in Chile, which should be fully operational in March, has already yielded unprecedented images of planet formation in progress. As new discoveries follow, astronomers expect to fill in more pieces of the puzzle, taking us ever closer to understanding how our planet, and by extension all of us, came to be. ●

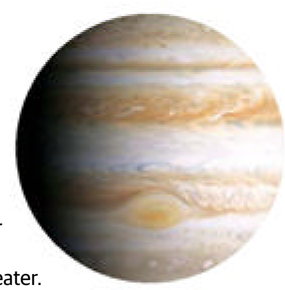
Types of planets

Terrestrial

Terrestrial planets like Earth and Mars are rocky planets with metal cores and high densities. They are smaller than gas giants and have slower rotation periods. In addition, their smaller size means they are less likely to have moons.

Gas giant

At a further distance from their orbiting star, gas giants are able to accrete more matter in their formation, giving them a large size and mass. For example, Jupiter is 11 times larger than Earth, and has a volume 1,300 times greater.



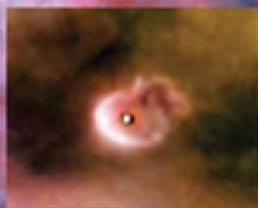
Dwarf planet

Smaller than a true planet, the difference between an asteroid and a dwarf planet comes down to its shape. To be a dwarf planet, a body must have sufficient mass to achieve hydrostatic equilibrium, when it will become spherical.

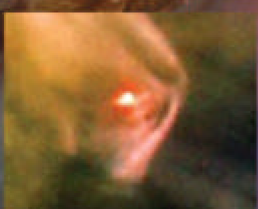
Planet formation in action

Our nearest star-forming region is the Orion Nebula, a massive cloud of gas and dust around 1,500 light years away. The striking nebula is visible to the naked eye - and positively breathtaking as seen through the Hubble Space Telescope. Hubble's sharp images, like this one from 2009, have revealed 42 protoplanetary discs (proplyds) where planet formation is now in progress. Theta^1 Orionis C, the nebula's brightest star, heats nearby proplyds, giving them a bright glow. Proplyds forming further away are too dim to see, but their dark dust blocks out parts of the bright nebula in the background, creating silhouettes astronomers can study.

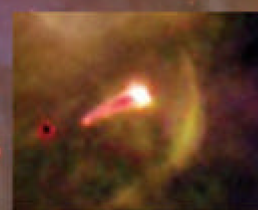
132-1832
Developing far from Theta^1 Orionis C, 132-1832 is one of the darker proplyds in the nebula



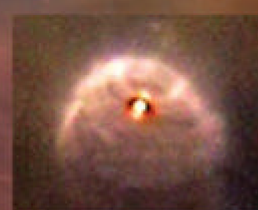
206-446
Astronomers believe this bright proplyd's distinctive ponytail-style plume is a jet of matter streaming out from the disc's centre



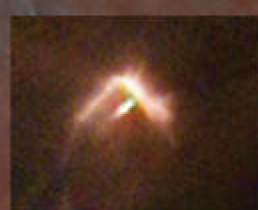
106-417
Stellar wind from the massive Theta 1 Orionis C interacting with gas has formed a shockwave around this ear-shaped proplyd



180-331
Proplyd 180-331, another bright disc near Theta^1 Orionis C, also sports a flowing jet of matter, giving it a tadpole shape



181-825
But the best shockwave sculpture has to be 181-825's distinctive galactic jellyfish form



231-838
Like 106-417, the bright proplyd 231-838 is surrounded by a shockwave, giving it a boomerang shape

"The origins of Jovian gas giant planets, like Jupiter and Saturn, are less certain"

What are asteroids made of?

The physical properties of huge space-rocks whirling around the Sun could hold clues to the origins of the Solar System

Protecting Earth is one of the main reasons why scientists keep a close eye on asteroids, which are space rocks of all shapes and sizes that can be found scattered throughout the Solar System.

It's unclear how meteoroids, the rocks that become meteors when they crash into Earth's atmosphere, were generated from asteroids. Still, NASA isn't ruling a link out and is examining asteroids to learn more about how the Solar System was formed.

Since planetary scientists believe planets gradually grew from rocks crashing into each other, the asteroid belt between Mars and Jupiter could be made up of the leftovers of the early Solar System.

Therefore, ferreting out the secrets of asteroids could also give scientists clues as to how the Solar System came to be. Possibly, it could even reveal how the Earth was born.

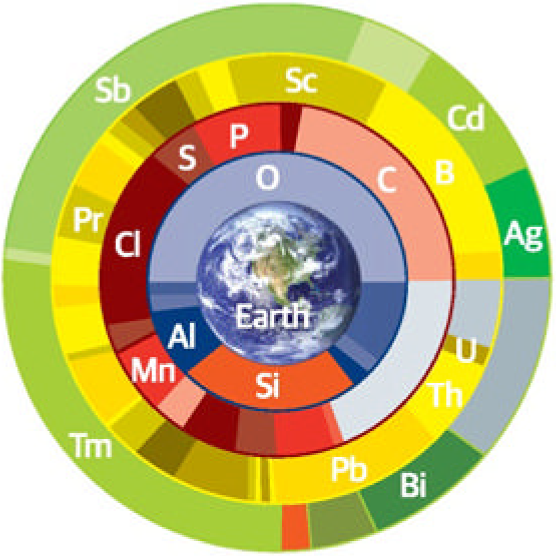
Studying asteroids is a challenge for scientists, however, because they are so small. A typical space rock is perhaps just a few metres across. However, the largest known asteroid in our Solar System, Ceres, is 950 kilometres (590 miles) in diameter and makes up a third of the mass of the known asteroid belt. However, through a telescope sitting on Earth, an asteroid of this size looks incredibly small. This makes asteroids difficult to see and study, but scientists are pretty crafty when it comes to getting information from a distance.

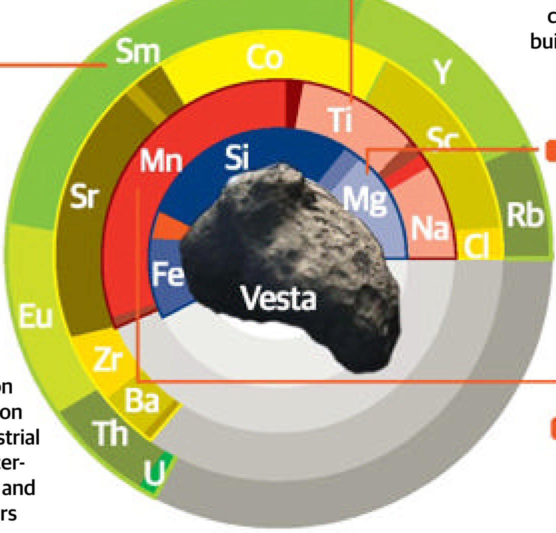
Most asteroids, according to NASA, can be classified in three groups: C-type (carbonaceous), S-type (siliceous) and X-type (various compositions). Around 75 per cent are C-type asteroids that lurk in the outer asteroid belt. They are very dark and probably lack helium, hydrogen and other lighter

"In 1995, there were only 335 known near-Earth asteroids, however, today there are more than 9,700 catalogued"


Asteroid Ida and its moon, Dactyl. The spacecraft Galileo discovered the small moon when it passed by the asteroid in 1994

Explaining the elements





Samarium
This element, which is rare on Vesta, is used on Earth for industrial magnets, cancer-fighting drugs and nuclear reactors

Titanium
This element could come in useful for building lightweight alloys for use in spacecraft

Magnesium
A very common element in the universe, it is used in fertilisers and to make magnesium-aluminium alloys

Manganese
An important element for stainless steel

Ag - Silver
Al - Aluminium
B - Boron
Bi - Bismuth
C - Carbon
Cd - Cadmium
Cl - Chlorine
Mn - Manganese
O - Oxygen
P - Phosphorus
Pb - Lead
Pr-Praseodymium
S - Sulphur
Sb - Antimony
Sc - Scandium
Si - Silicon
Th - Thorium
Tm - Thulium
U - Uranium

Ba - Barium
Co - Cobalt
Cl - Chlorine
Eu - Europium
Fe - Iron
Mg - Magnesium
Mn - Manganese
Na - Sodium
Rb - Rubidium
Sc - Scandium
Si - Silicon
Sm - Samarium
Sr - Strontium
Th - Thorium
Ti - Titanium
U - Uranium
Y - Yttrium
Zr - Zirconium

Asteroids can range from just a few metres wide to almost 1,000km in diameter

'volatile' elements. S-type asteroids, about 17 per cent of the population, make up most of the inner belt rocks in the asteroid belt. They're a little more reflective and are usually made of metallic iron mixed with silicates of iron and magnesium. Squeezed in between these asteroids are X-types, which are mostly made up of metallic iron asteroids and the like. These are found in the middle of the asteroid belt.

While most asteroids sit safely between Mars and Jupiter, some approach Earth and sometimes cross its orbit. Scientists think most of these asteroids were 'disturbed' into different orbits due to Jupiter's gravity or collisions with other asteroids.

There are three types of near-Earth asteroids. Amors cross the orbit of Mars, but don't get very close to Earth. Apollos cross Earth's orbit in a period of one year or longer, while Atens also cross the orbit but in a shorter time frame - a year or less.

In the past two decades, space agencies and observatories around the world have discovered thousands of these types of asteroids. In 1995, there were only 335 known near-Earth asteroids, however, today there are more than 9,700 catalogued, according to NASA.

Since scientists believe we have now found more than 90 per cent of threatening asteroids that are more than one kilometre (0.6 miles) in diameter, NASA is now emphasising the search for finding near-Earth objects of 140 metres (460 feet) or greater.

Still, a much smaller object can cause a lot of damage. The dinosaurs were probably wiped out by a small body just ten kilometres (6.2 miles) in diameter that hit the Mexico area about 66 million years ago.

In Russia this year, more than 1,000 people were injured when a house-sized asteroid - 17 metres wide (56 feet) - detonated in the atmosphere. The event caught both the public and astronomers by surprise, demonstrating we still have a lot to learn about predicting meteor strikes on Earth.

In more recent years, several space missions have ventured out to asteroids to get more information from closeup. NASA's Dawn mission, for example, scooted by the asteroid Vesta in 2011 and is now en route to Ceres.

Its closeup views revealed a battered world that, surprisingly, has some links to how the Moon was formed. Vesta and the Moon were each peppered by a population of space rocks ejected into the inner Solar System early in the Earth's history.

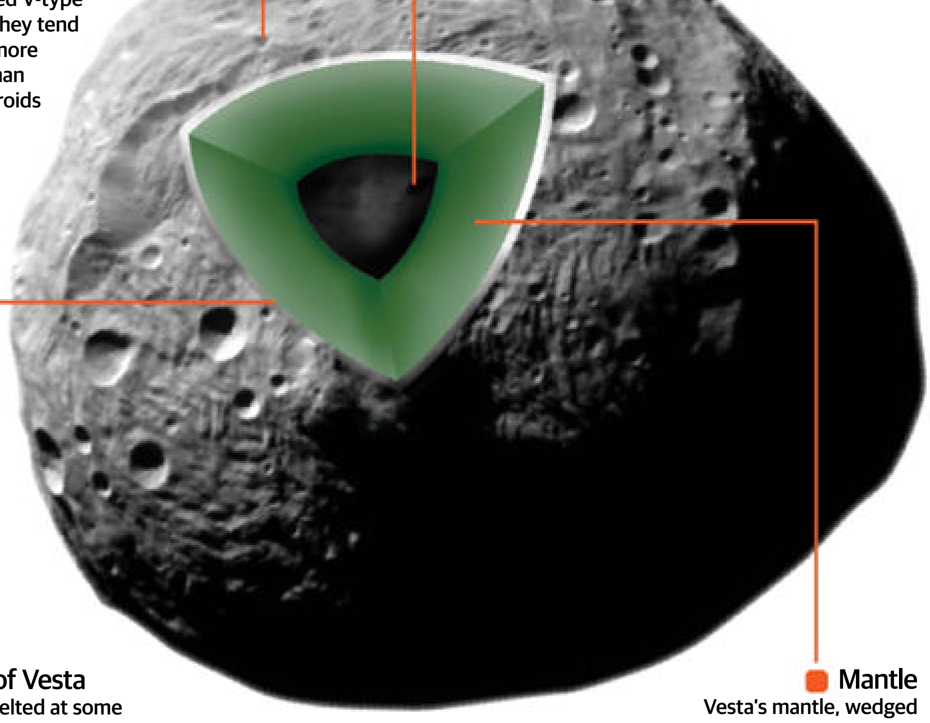
Both Jupiter and Saturn shifted their orbits in less than a million years. Their motions perturbed the asteroid belt and sent the rocks into planet-crashing orbits. This bombardment had been known about for decades - astronauts on the Apollo missions even discovered evidence of it on the Moon - but scientists didn't know until recently that Vesta had also experienced it.

The next step will be obtaining a sample of an asteroid and studying it here on Earth. Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) will journey into space in 2016, scoop up a bit of dirt from the Apollo asteroid (101955) 1999 RQ36, and return it to Earth by 2023 for further investigation.

What lies inside

Asteroid Vesta
Vesta, the second-most-massive asteroid in the Solar System, stands in a class of its own called V-type asteroids. They tend to contain more pyroxene than S-type asteroids

Core
Data from the Dawn mission showed that Vesta has a core of 110km (68mi) in radius. The core is mostly made up of iron



Crust of Vesta
Vesta melted at some point early in its history, producing a 'differentiated' core and a basaltic crust

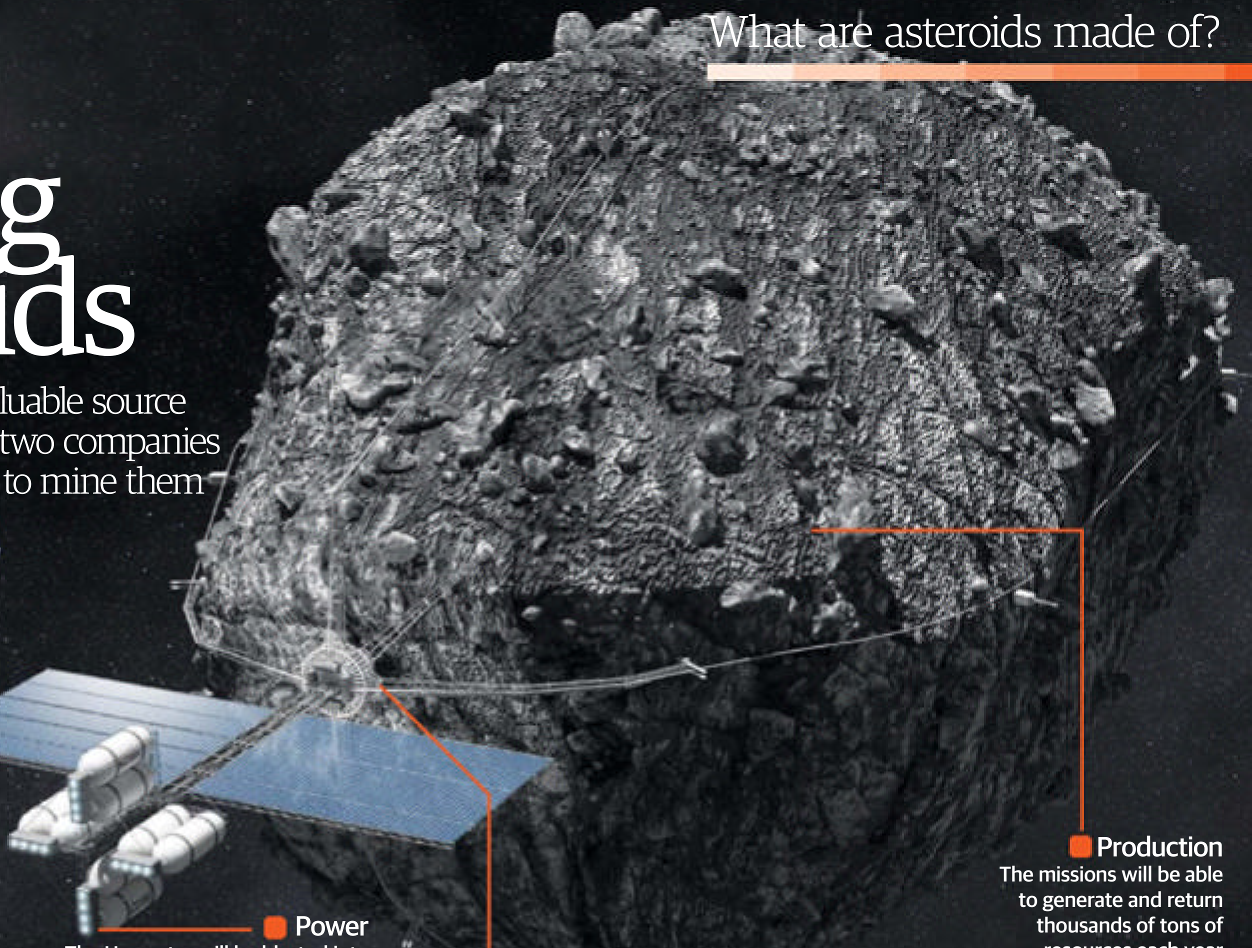
Mantle
Vesta's mantle, wedged between the core and crust, likely includes olivine and diogenite

Mining asteroids

Asteroids could be a valuable source of resources and so far two companies have announced plans to mine them

Deep Space Industries

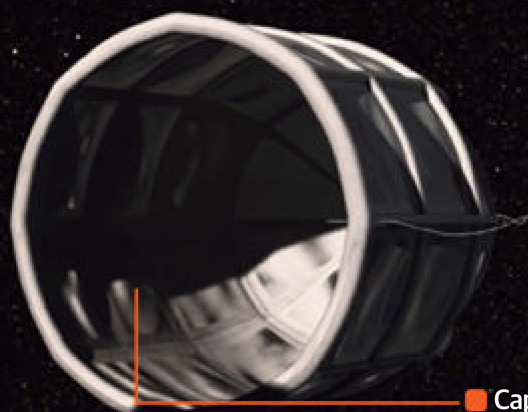
Deep Space Industries plans - at some point - to send robotic probes on a one-way reconnaissance mission to potential asteroid mining sites. Later, larger DragonFly spacecraft would potentially pick up samples or small asteroids for further evaluation on Earth.

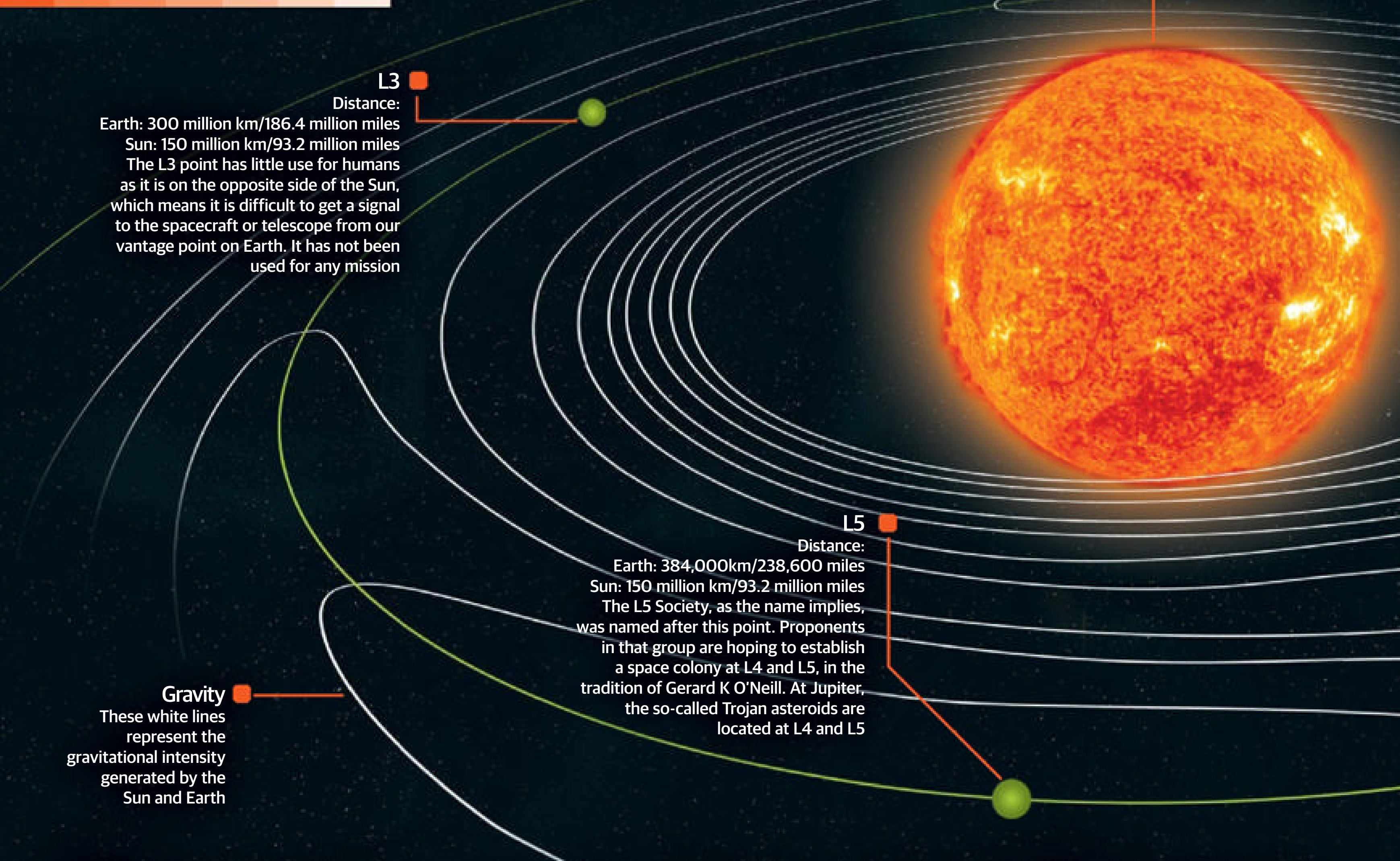


Deep Space Industries plans to use its Harvester to mine vital resources from asteroids

Planetary Resources

Planetary Resources first plans to scope out potential asteroids using a telescope. They will then capture a suitable asteroid and reposition it in a stable orbit near Earth, before sending a fleet of robotic spacecraft to return samples from the surface. They expect to begin surveying asteroids in the coming years.





Lagrange points

Lagrange points are the spots where the gravity of two bodies - say, the Earth and the Moon - exactly balance each other out, a phenomenon that makes them very useful for research

NASA defines these areas as spots where a small body - such as a spacecraft - can stay in a consistent orbit between two very large masses, such as two planets or a planet and a large moon.

When standing above Earth and looking around, it's pretty straightforward to locate the five points. L1 is directly in front of Earth, between the Earth and the Sun. Extrapolating along the same line, L2 is behind Earth and L3 behind the Sun.

These three locations were first computed by Leonhard Euler around the 1770s, but as the name implies, the Lagrange points were actually named after French-Italian mathematician Joseph Lagrange.

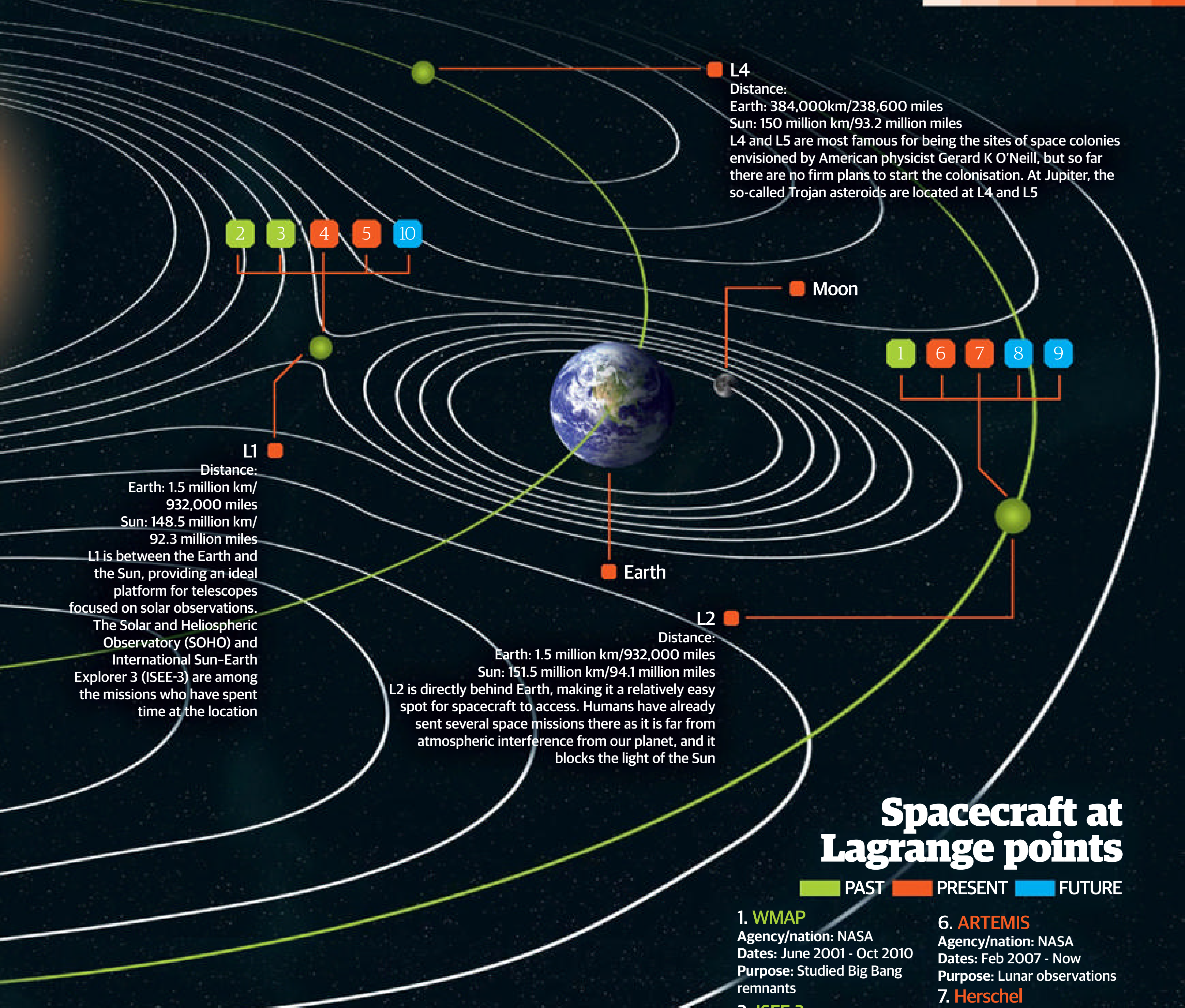
A few years after Euler, Lagrange also found two other stable locations - known as L4 and L5 - at spots that are approximately 60 degrees from both the Earth and the Sun.

Space-faring nations have already sent several telescopes to Lagrange points near Earth, because they are far from interference from Earth's atmosphere and heat. Only L4 and L5 are stable locations, but with a little extra fuel a telescope can happily sit at any of the Lagrange points for years. Some of the more famous Lagrange residents include the Solar and Heliospheric Observatory (SOHO) - which keeps an eye on the Sun at L1 - and the James Webb Space Telescope, which will launch to L2 around 2018.

NASA has said that it has no real use for the L3 Lagrange point near Earth, although it has been the source of some psuedo-scientific speculation throughout recent years. "It remains hidden behind the Sun at all times," NASA wrote on its website, but added a tongue-in-cheek reference to what could be lurking there. "The idea of a hidden 'Planet-X' at the L3 point has been a popular topic in science fiction writing. The instability of Planet X's orbit (on a time scale of 150 years) didn't stop Hollywood from turning out classics like *The Man From Planet X*," the agency wrote.

While we most often think of the five Lagrange points located around the Earth, these points are possible between any celestial bodies that are massive enough. Jupiter, for example, has asteroids at its L4 and L5 points with the Sun. These are called Trojan asteroids.

German astronomer Max Wolf spotted the first of these asteroids in 1906. More than 100 years later, in 2012, NASA's Wide-field Infrared Survey Explorer revealed that these bodies are mostly burgundy in colour, and reflect little sunlight.



L4
Distance:
Earth: 384,000km/238,600 miles
Sun: 150 million km/93.2 million miles
L4 and L5 are most famous for being the sites of space colonies envisioned by American physicist Gerard K O'Neill, but so far there are no firm plans to start the colonisation. At Jupiter, the so-called Trojan asteroids are located at L4 and L5

L1
Distance:
Earth: 1.5 million km/932,000 miles
Sun: 148.5 million km/92.3 million miles
L1 is between the Earth and the Sun, providing an ideal platform for telescopes focused on solar observations. The Solar and Heliospheric Observatory (SOHO) and International Sun-Earth Explorer 3 (ISEE-3) are among the missions who have spent time at the location

L2
Distance:
Earth: 1.5 million km/932,000 miles
Sun: 151.5 million km/94.1 million miles
L2 is directly behind Earth, making it a relatively easy spot for spacecraft to access. Humans have already sent several space missions there as it is far from atmospheric interference from our planet, and it blocks the light of the Sun

Spacecraft at Lagrange points

PAST PRESENT FUTURE

1. WMAP
Agency/nation: NASA
Dates: June 2001 - Oct 2010
Purpose: Studied Big Bang remnants

2. ISEE-3
Agency/nation: NASA/ESA
Dates: Aug 1978 - May 1997
Purpose: Studied Sun-Earth interaction

3. GRAIL
Agency/nation: NASA
Dates: Sept 2011 - Dec 2012
Purpose: Used L1 en route to the Moon

4. WIND
Agency/nation: NASA
Dates: Nov 1994 - Now
Purpose: Studying solar wind

5. SOHO
Agency/nation: NASA
Dates: Dec 1995 - Now
Purpose: Solar observations

6. ARTEMIS
Agency/nation: NASA
Dates: Feb 2007 - Now
Purpose: Lunar observations

7. Herschel
Agency/nation: ESA
Dates: May 2009 - Now
Purpose: Infrared observations

8. Gaia
Agency/nation: ESA
Dates: Sept 2013
Purpose: Catalogue stars

9. JWST
Agency/nation: NASA/ESA/CSA
Dates: 2018
Purpose: Infrared observations

10. Solar-C
Agency/nation: JAXA
Dates: 2018
Purpose: Solar observations


SOHO is a solar-observing telescope that is located at Lagrange point L1


The James Webb Telescope will launch in 2018 and be located at L2

DEADLY SPACE JUNK

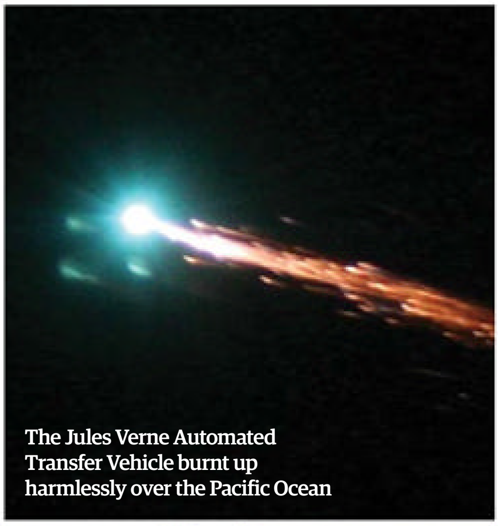
Hurtling around the Earth at thousands of kilometres per hour, out-of-control space debris can have a devastating effect on anything that crosses its path

It's perhaps the most electrifying sequence in the awe-inspiring blockbuster film *Gravity* – the moment a blizzard of incoming space debris travelling at terrifying speed lays waste to everything in its path, destroying both the International Space Station and an orbiting Space Shuttle, leaving two spacewalking astronauts adrift and fighting for their lives.

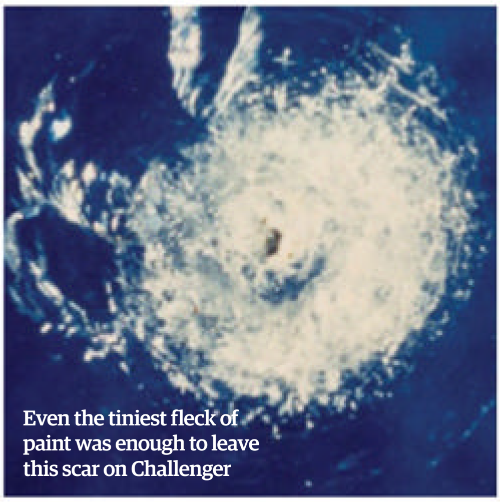
Fortunately, though, it's the kind of thing that could only happen in a movie… or is it? While the debris storm in *Gravity* is created by a foolhardy missile test on a defunct satellite, space scientists today are increasingly concerned that something very similar could happen by accident, with a runaway cascade of collisions leaving large areas of near-Earth space dangerously inaccessible. If that happens, the effects wouldn't just be felt by a few orbiting astronauts – we could all suffer the substantial consequences.

Ever since the launch of the first satellite, Sputnik 1, back in 1957, humankind has been steadily filling up the space around Earth. Official figures put the number of satellites sent into orbit since the dawn of the Space Age at nearly 7,000 and there are probably a few unacknowledged ones lurking around from the secretive days of the Cold War.

While many of these objects have since re-entered Earth's atmosphere and burnt up – thanks to either



The Jules Verne Automated Transfer Vehicle burnt up harmlessly over the Pacific Ocean



Even the tiniest fleck of paint was enough to leave this scar on Challenger

unstable initial orbits or the slight but inexorable drag of sparse gas in the upper atmosphere – an estimated 2,000 are still circling Earth today.

Given the sheer volume of space available around Earth, that might not seem like a large number, but there's a catch – satellites tend to cluster together in a much smaller number of particularly useful orbits. Low Earth Orbit (LEO), for example, is the zone just a couple of hundred kilometres above the surface that's most easily reached by manned spaceflight and also most useful for many Earth-observing satellites.

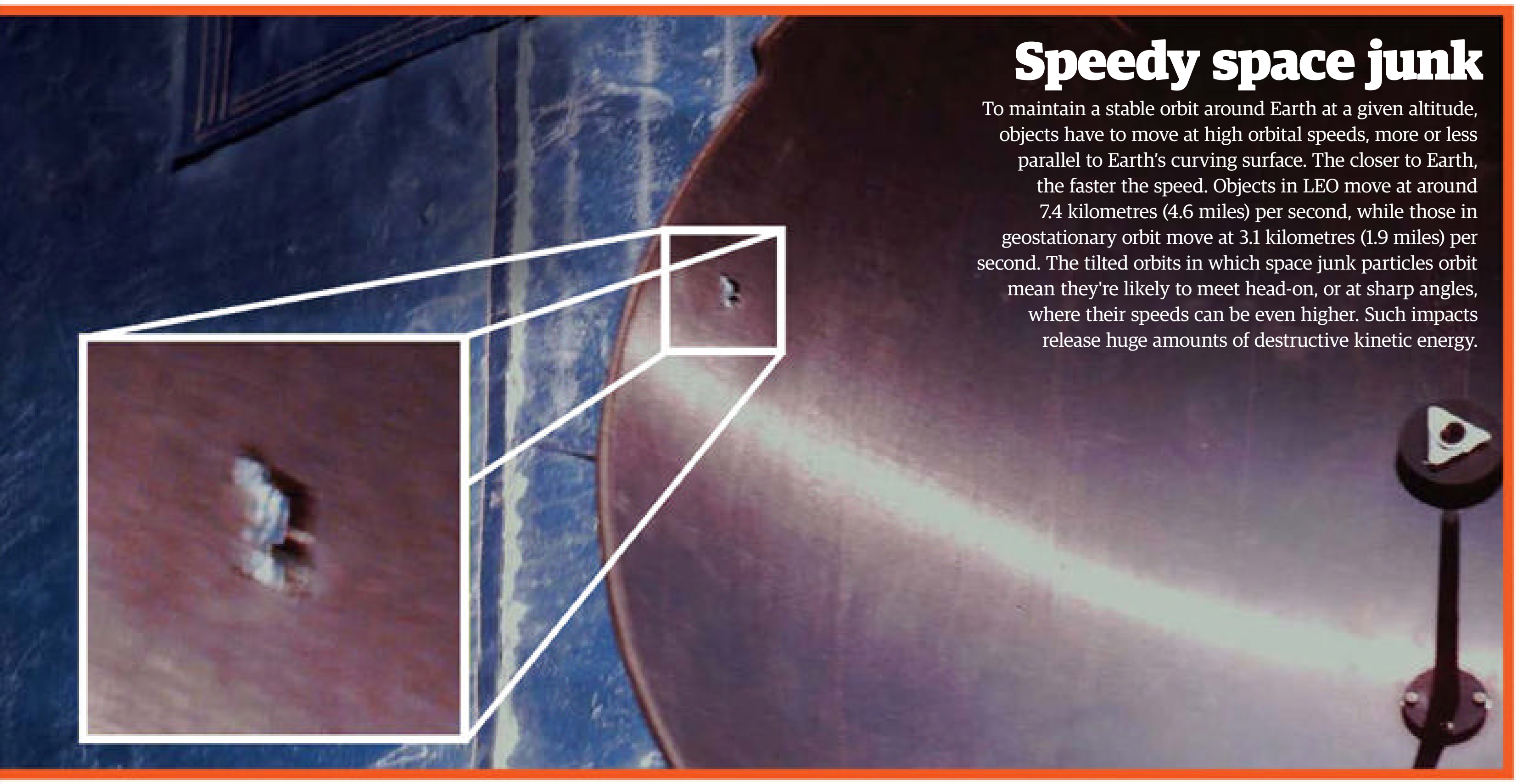
Geostationary orbit, meanwhile, is a very specific circular orbit 35,786 kilometres (22,236 miles) above the equator, in which satellites orbit the Earth in the same period as the planet itself rotates (23 hours, 56 minutes), therefore maintaining a fixed position in the sky as seen from Earth. The majority of weather satellites use this orbit, as well as telecommunications satellites that form such an essential part of the modern global infrastructure.

What's more, launching anything into orbit is a messy business, so even if the lower stages of a rocket simply arc into space before plunging back to Earth, there's every chance they could leave more behind than their intended payloads. Explosive bolts fired to separate launch vehicle components and the ignition of further stages may shake loose chips of paint and even larger fragments of rocket casings, flinging them into their own unpredictable orbits around Earth. Another major problem is that spent rocket casings, languishing idly in orbit, can suffer from spontaneous yet hazardous explosions.

Both NASA and the European Space Agency have programmes dedicated to tracking orbital debris – NASA's Ground-based Electro-Optical Deep Space Surveillance (GEODSS) project searches for material using an array of computerised optical telescopes and super-sensitive television cameras. The technology can only track objects of roughly ten centimetres (four inches) in diameter (with a mass typically around a kilogram, or 2.2 pounds), but GEODSS has so far identified 22,000 different objects in this class. Based on this figure, statistics suggest there could be as many as 500,000 objects in the one to ten-centimetre (0.4 to four-inch) range, plus tens of millions of smaller particles. Other surveys aim to use ground-based radar to track objects too small to be seen by optical telescopes. Maps produced using this data show our planet already surrounded by an alarming halo of debris.

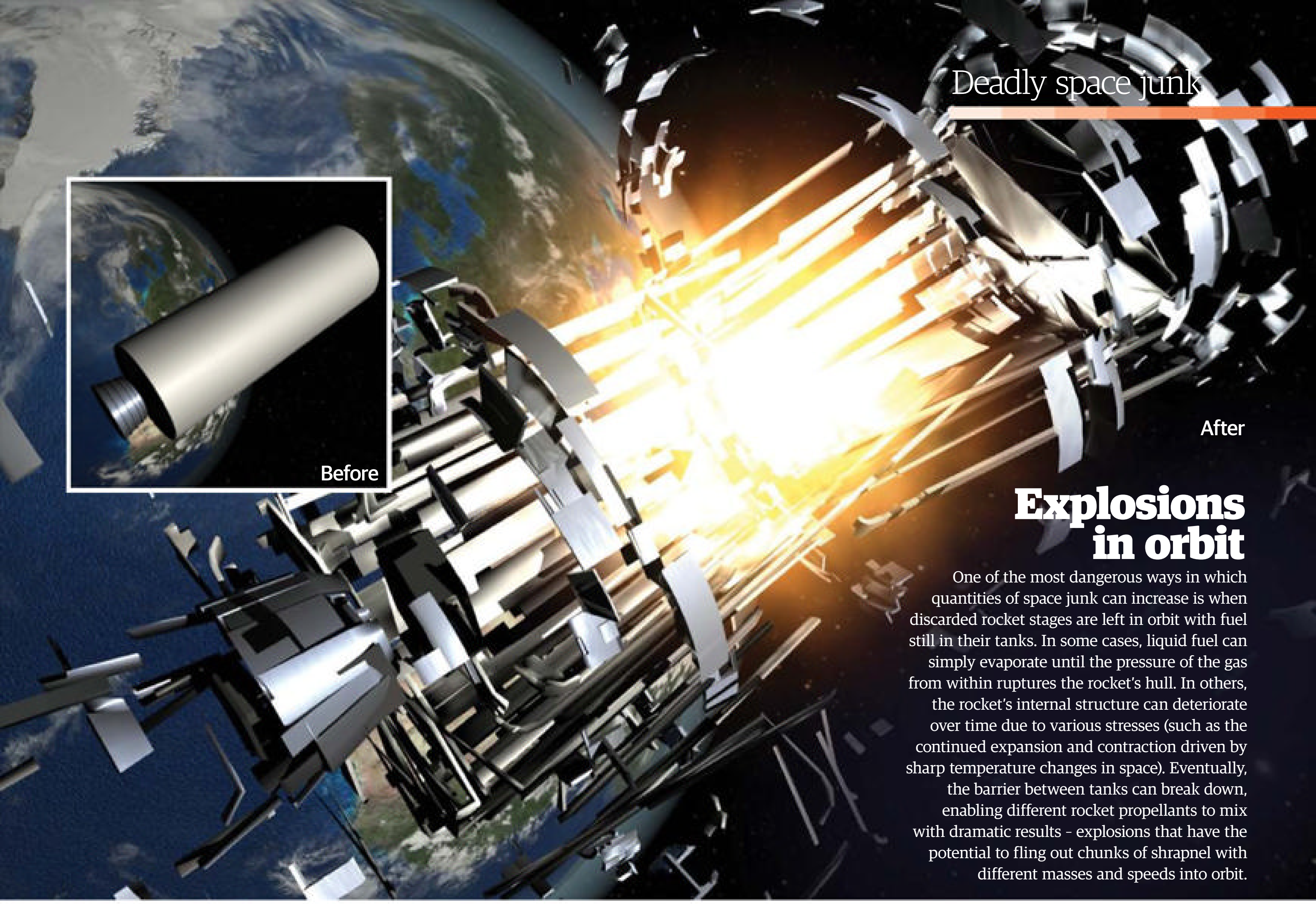
Perhaps it's little wonder, then, that collisions happen. Space scientists received an alarming wake-up call to the growing threat in 1983 when the Space Shuttle Challenger returned to Earth with a substantial crater in one of its reinforced windows. Careful study of the damage back on Earth determined that it was caused by an insubstantial fleck of paint, colliding with the shuttle at several kilometres per second – it's the hypervelocity speed of encounters in orbit that enables even lightweight objects to pack such an unexpected punch.

What's worse, the fairly frequent shuttle flights up to the end of the last decade gave engineers a chance to make regular assessments of the likelihood of impacts in LEO and provided clear evidence that the problem was getting worse – particularly since the late-1990s. In 2006, Atlantis was struck by a tiny object that bored a hole straight through one of the radiator panels on the cargo bay door, while in 2007 Endeavour came home sporting a hole several centimetres across in the same area, that triggered more than a slight cause for concern.



Speedy space junk

To maintain a stable orbit around Earth at a given altitude, objects have to move at high orbital speeds, more or less parallel to Earth's curving surface. The closer to Earth, the faster the speed. Objects in LEO move at around 7.4 kilometres (4.6 miles) per second, while those in geostationary orbit move at 3.1 kilometres (1.9 miles) per second. The tilted orbits in which space junk particles orbit mean they're likely to meet head-on, or at sharp angles, where their speeds can be even higher. Such impacts release huge amounts of destructive kinetic energy.



Explosions in orbit

One of the most dangerous ways in which quantities of space junk can increase is when discarded rocket stages are left in orbit with fuel still in their tanks. In some cases, liquid fuel can simply evaporate until the pressure of the gas from within ruptures the rocket's hull. In others, the rocket's internal structure can deteriorate over time due to various stresses (such as the continued expansion and contraction driven by sharp temperature changes in space). Eventually, the barrier between tanks can break down, enabling different rocket propellants to mix with dramatic results – explosions that have the potential to fling out chunks of shrapnel with different masses and speeds into orbit.

An even more impressive collision took place in 2009, when Iridium 33 – part of the US satellite telephone network – collided with the defunct Russian communications satellite Kosmos-2251 at high speed. The two satellites were travelling almost perpendicular to each other and, in the months that followed, NASA tracked a spreading field of more than 2,000 substantial debris fragments. In March 2012, astronauts aboard the International Space Station were forced to take shelter, ready for an emergency return to Earth, as a fragment of the Russian satellite passed nearby.

Various space agencies have also done their best to add to the problem from time to time. The earliest example of deliberate orbital littering came with Project West Ford in 1963 – an attempt to scatter a ring of almost 500 million tiny magnetic needles around the Earth. It was thought this would form an artificial ionosphere – a reflecting layer for bouncing military signals between distant locations. Other shocking examples include the deliberate destruction of satellites during anti-satellite missile tests. China's destruction of its Fengyun-1C satellite during a 2007 weapons trial still holds the ignominious record as the source of the largest amount of catalogued debris.

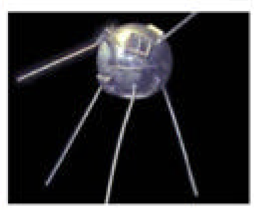
Fortunately Earth's atmosphere provides a natural clean-up mechanism in the form of friction with the upper atmosphere or exosphere. Although objects in orbit can usually be considered as outside the atmosphere, the thin shell of gases has no abrupt edge – instead it extends out for thousands of kilometres, growing ever thinner. Friction caused by collisions with these sparse gas molecules gradually slows the orbits of satellites, dropping them closer to Earth, where they experience increasing friction. As a result, with no external intervention, most satellite orbits inevitably decay and objects re-enter the atmosphere. However, atmospheric drag is only really effective at clearing out orbits below about 800 kilometres (500 miles).

In the early days of space exploration, engineers mistakenly assumed that orbital decay would drain debris from orbit quicker than it could accumulate, but they reached this conclusion without considering two significant factors. The first of these is simply the increased accessibility of space and the number of satellite launches. The second, and more alarming problem, is the so-called Kessler effect.

Named after NASA scientist Donald Kessler, who in the 1970s predicted the development of a fully

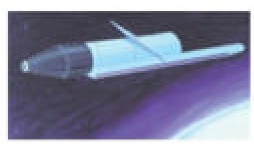
> "Earth's atmosphere provides a natural clean-up mechanism in the form of friction with the upper atmosphere"

Left in space



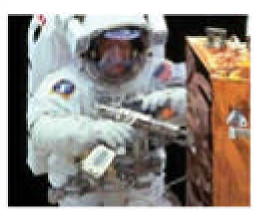
Vanguard 1

The oldest piece of space junk still in orbit is Vanguard 1, the second US satellite. It stopped transmitting signals to Earth in 1964, but is likely to remain in orbit for another two centuries.



Orbiting reactors

RORSAT was a series of spy satellites launched by the Soviet Union between 1967 and 1988. While the satellites have re-entered the atmosphere, their reactor cores were ejected into higher orbits.



Lost tools

Space Shuttle astronauts had to cope with the embarrassing sight of a number of tools drifting away into space, including wrenches, pliers and on one occasion an entire toolbag!

Space junk through the years

Since our first forays beyond the Karman line, around 100 kilometres (60 miles) above sea level, we've sent an exponential stream of objects, instruments and spacecraft into various levels of Earth orbit. For the best part of that time, we've not even thought about the mess we've been making up there or the consequences of space junk in the future.

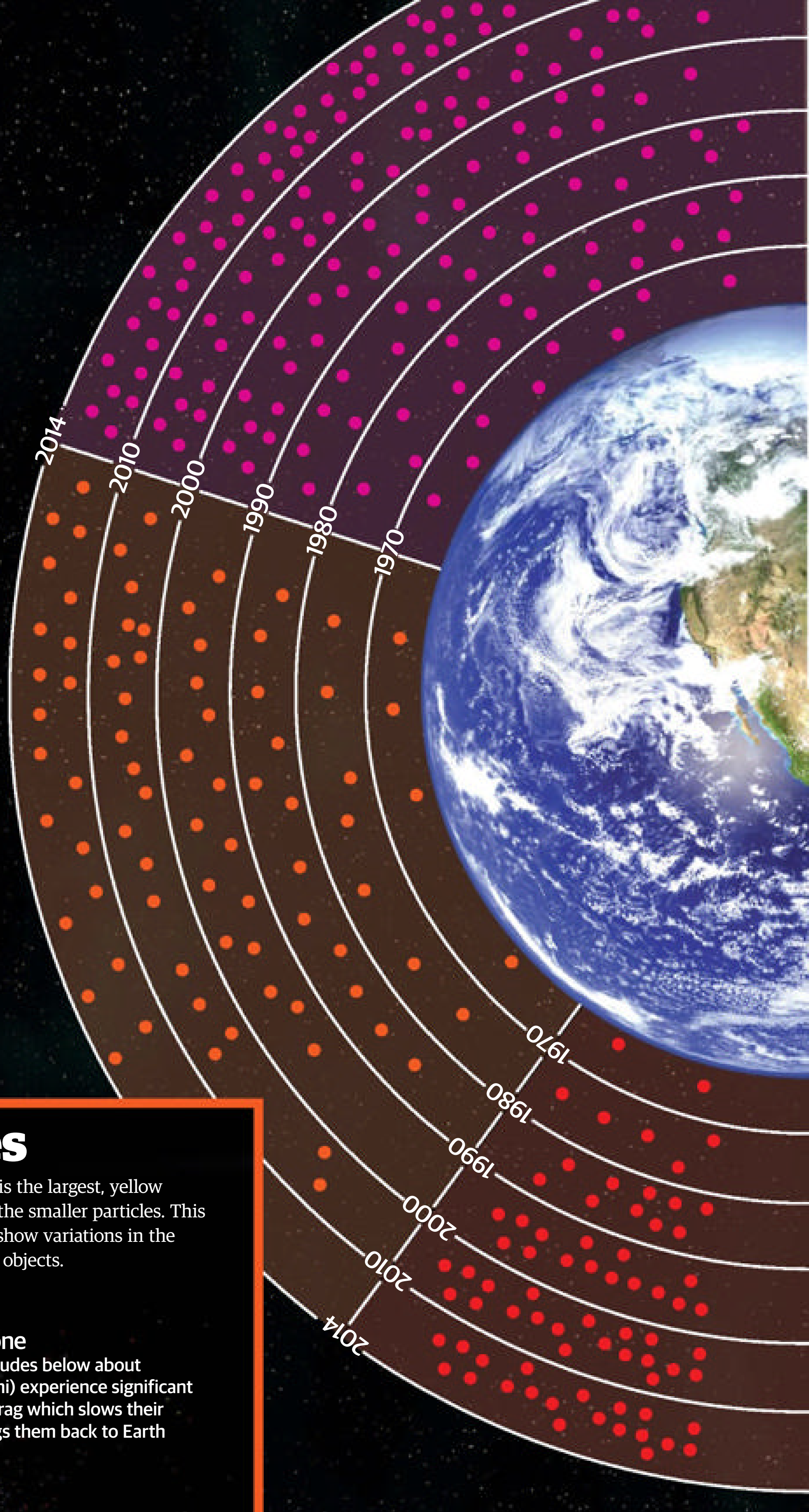
Both the amount and different types of junk has increased dramatically in the last 30-40 years since the Apollo missions. Here's the kind of dangerous scrap every new space mission faces in orbit today...

Key

- Each dot represents 100 objects with a diameter of more than 10cm

Type of debris

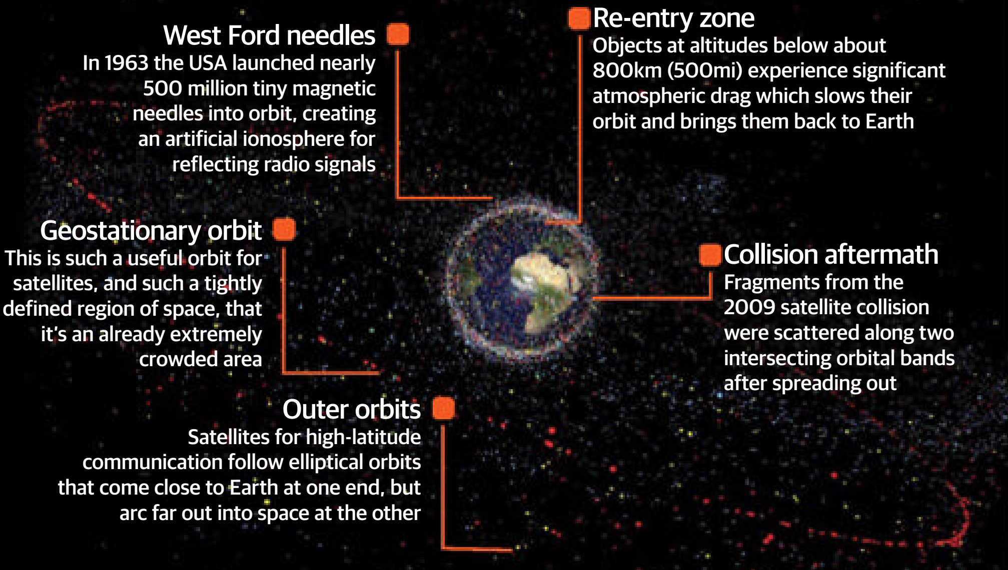
- Payloads
- Payload debris
- Rocket mission-related objects
- Rocket debris
- Rocket bodies



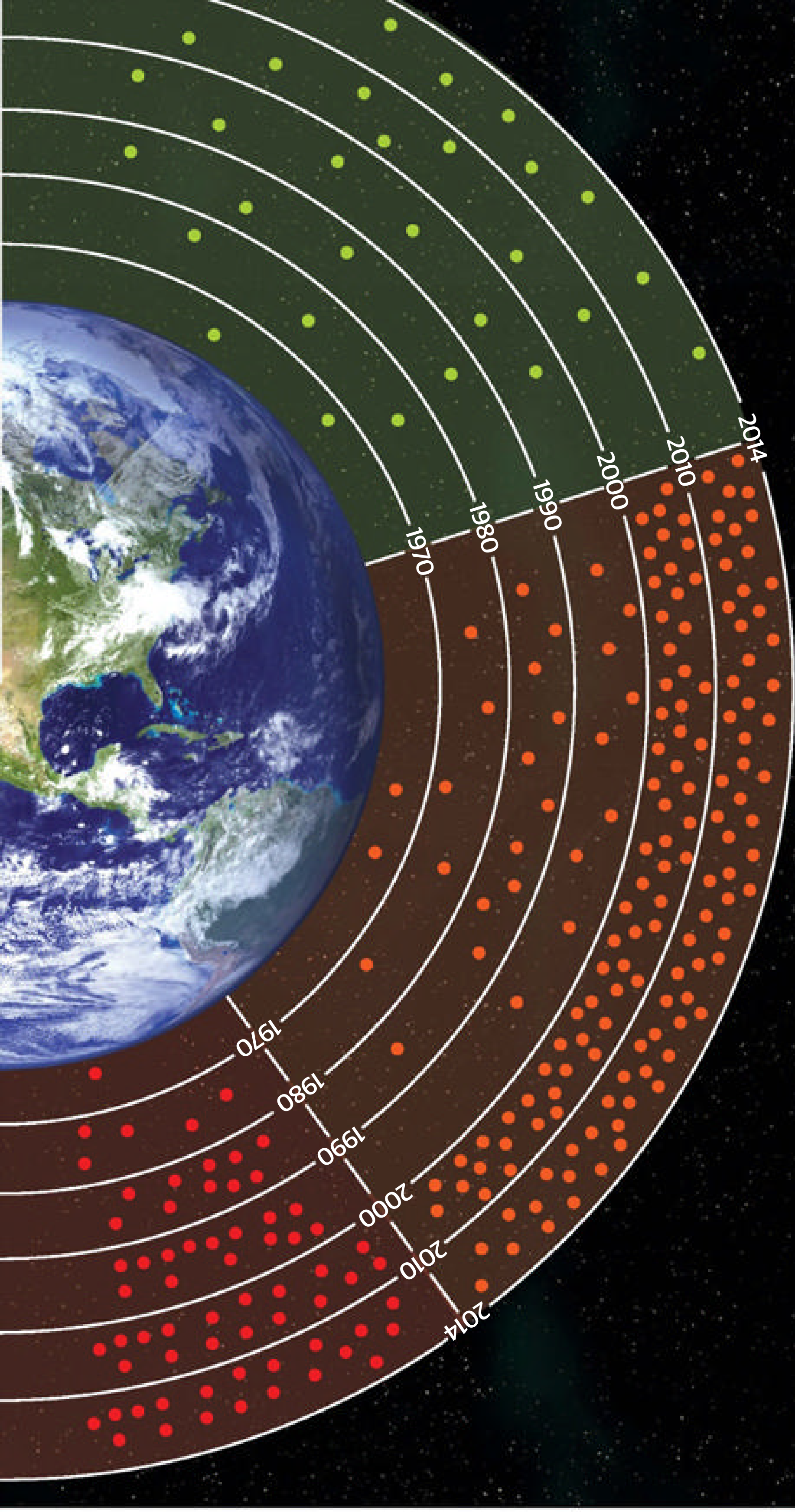
Earth's deadly debris zones

This artist's impression attempts to visualise the crowded space around the Earth, highlighting the busiest regions, including LEO and geostationary orbits. Different sizes of object are represented in various colours: red is the largest, yellow intermediate and blue the smaller particles. This view only attempts to show variations in the distribution of orbiting objects.

Key > 10cm > 1cm > 1mm



blown debris belt around the Earth by the turn of the millennium, Kessler syndrome is an effect in which, once the debris belt has reached a certain critical density, an initial collision between two large objects can give rise to a cascade, or avalanche, effect. This results in shrapnel being flung out from the first collision, hitting other objects in nearby orbits and generating yet more debris. Kessler was the first to recognise that one of the crucial factors controlling the density of objects was the rate of collisions between them, since a single high-energy collision shattering an asteroid could produce countless



Space junk: the figures

22,000
The number of large objects less than 10cm across being tracked in Earth orbit by NASA's GEODSS system

500K
Statistical estimate of the mid-sized fragments (1-10cm across) in orbit around Earth

3mm
Size of the smallest debris fragments that can be seen by Earth-based radar monitoring

1 in 200
NASA's upper risk limit to the chances of a collision with a piece of debris on a mission

13,000
The estimated number of close calls that occur every week

8,211kg
The mass of the Envisat satellite stranded in a crowded region of Low Earth Orbit

3,000
Number of trackable debris pieces created by the 2007 anti-satellite test

42,120km/h
Speed of the 2009 collision between Iridium 33 and Kosmos-2251

fragments, each of which, though small, might potentially be fatal to a spacecraft.

This is the kind of event dramatised in that pivotal sequence from *Gravity* and its overall result could be to render large areas of Earth orbit inaccessible for many years. While it's unlikely that a Kessler cascade could block access to space completely, it could make it harder to reach certain types of useful orbit and limit the operational lifetime of satellites after their deployment. These are all factors that could significantly affect everyday technologies such as satellite navigation, telephony and broadcasting, as well as limiting scientific missions such as Earth remote sensing and orbiting astronomical telescopes.

So, in little more than five decades of spaceflight, we've already reached a situation in which space junk is a very real threat. It's one that's only likely to get worse in the future unless we take global action not just to improve our littering habits, but also to remove the material that's already there.

Satellites are increasingly being designed with the facility to boost into a safe, remote graveyard orbit at the end of their useful lives, or to deliberately deorbit, ensuring a safe, controlled breakup in the atmosphere. Efforts have also been made to limit the dangers from potentially explosive debris left in orbit. There's even talk of regulating commercial satellite companies with a 'one up, one down' rule, so it's in their financial interest to ensure defunct spacecraft are safely and cleanly dealt with. The International Telecommunication Union (ITU), responsible for regulating comsats in geostationary orbit, has been particularly keen to ensure this valuable and very precise orbit is maintained for future use.

So, how can we clear out all the junk that's already up there? Various ideas have been put forward,

including automated tug spacecraft capable of boosting geostationary satellites into a graveyard orbit, or even returning them to Earth. However, this kind of mission would only really be practical for handling the largest pieces of debris – shifting material between orbits would require large amounts of propellant, so the tug design itself would require an infrastructure for refuelling in orbit.

An ingenious alternative, developed by researchers at Texas A&M University, is the Sling-Sat – a fuel-efficient mission that would involve a spinning satellite briefly capturing debris before flinging it away on a safe path towards de-orbit. Each interaction with a debris particle would increase the satellite's momentum, enabling it to remain in operation for a long period of time.

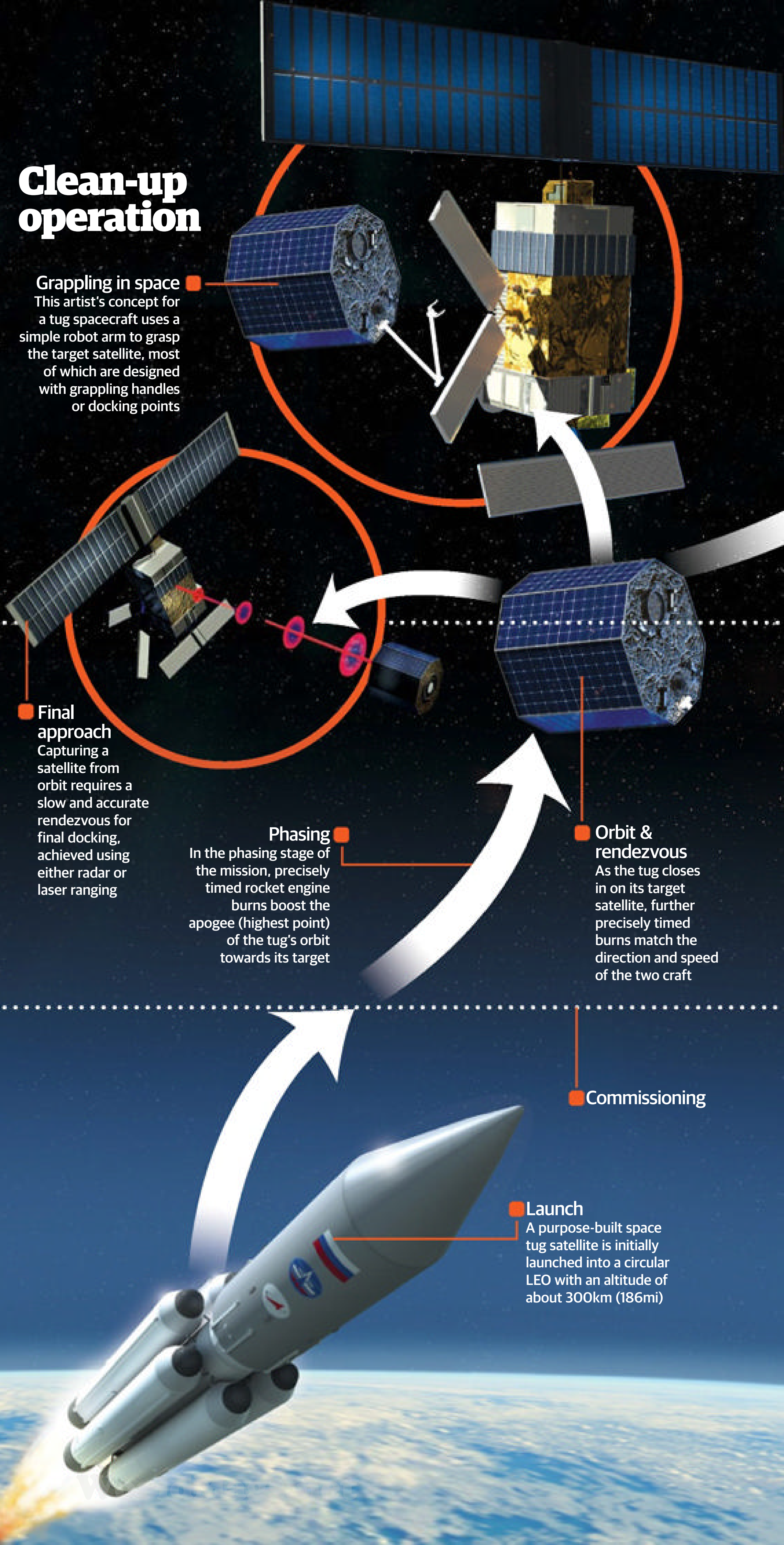
Dealing with the countless smaller debris fragments is a much greater challenge, so for practical reasons any clean-up operations will almost certainly be limited to certain specific clusters of small debris, such as those left behind by Project West Ford.

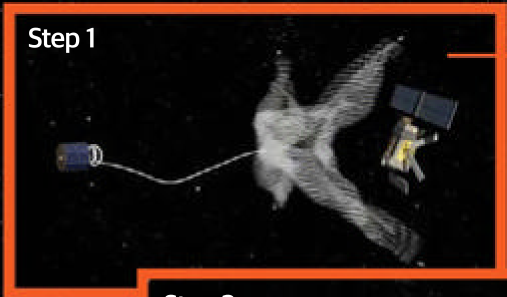
Many proposals involve deploying the space-based equivalent of a butterfly net. In February 2014, a joint US-Japanese satellite launched into orbit carrying a prototype for one such design. The Space Tethered Autonomous Robotic Satellite 2 (STARS-2) mission involves the deployment of a small subsatellite at the end of a 300-metre (984-foot) tether cable. Using the same principle as a bicycle dynamo, this tether will generate electric current as it passes through Earth's magnetic field and the resulting electromagnetic field around it should attract nearby debris particles, rather like a balloon with a static charge attracting dust. If the trial goes according to plan, a full-scale version could be in operation by 2019.

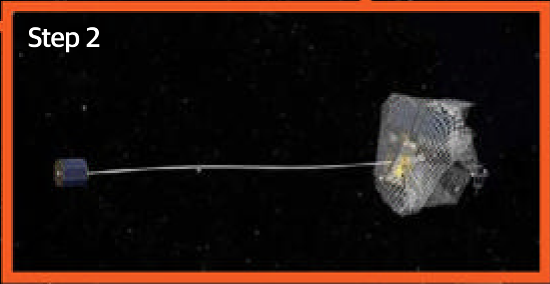
Another widely touted alternative is known as the laser broom, involving firing a medium-powered laser from the ground towards the front of debris particles. Working on the same principle as solar sail propulsion, the laser would apply a tiny braking force to the target object, gradually draining its momentum and pushing it onto a new orbit. Studies suggest that a laser broom could adjust the orbit of small objects by a couple of hundred metres over a few hours – enough to avoid potential collisions, while repeated use could nudge an object towards eventual deorbit. The accurate targeting of such small and fast-moving objects would be a major challenge so, for the moment at least, laser brooms might be most appropriate as a last line of defence for space stations.

One thing, it seems, is certain – with new players entering the field of space exploration and the valuable real estate of Earth orbit becoming ever more crowded, space junk isn't a problem that's about to go away any time soon – it's quite literally an accident waiting to happen.

Clean-up operation

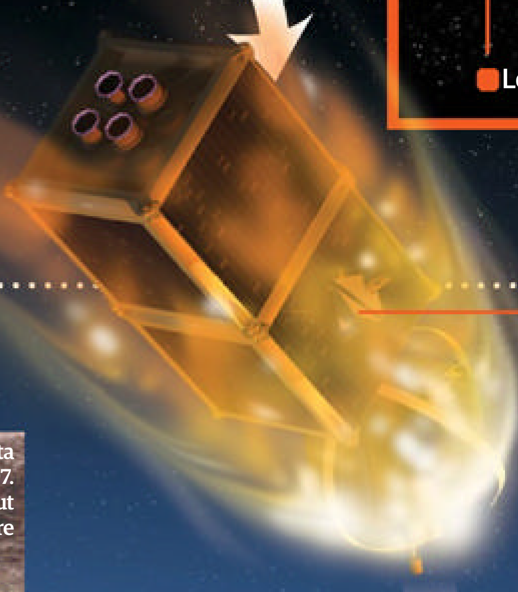






Trawling in orbit
Another possible way of capturing a satellite, illustrated in these two steps, involves the deployment of a large net or basket at the end of a long, flexible tether. Once the satellite is secured, the final phase of the mission can begin

Target orbit



Perigee lowering
The tug spacecraft reorients itself in space so that engine burns gradually slow its orbital momentum and lower its perigee (closest point to Earth)

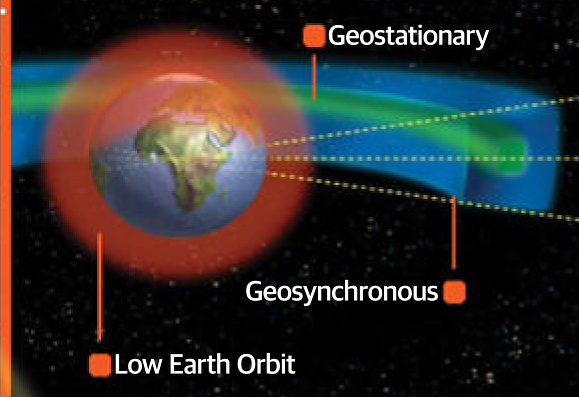
De-orbit burn
With the perigee skimming the thicker layers of Earth's atmosphere, a final engine burn puts the tug and its cargo on target for re-entry

Re-entry
Depending on the size of the spacecraft involved, both satellites may break apart and burn up amid the stresses of atmospheric re-entry. Alternatively, the de-orbit burn can be timed to ensure that any surviving fragments crash into the open ocean

Protected orbits?

Since 1993, most of the world's major space agencies have been members of the Inter-Agency Space Debris Coordination Committee (IADC), a co-operative effort to research the effects of space debris and look at ways of resolving the problem.

One of their key proposals, first outlined in 2002, is the creation of protected orbital regions – zones where special efforts would be made to avoid debris creation – and to remove defunct satellites once their useful lifetime is at an end. The two key zones are LEO (defined as everything below an altitude of 2,000 kilometres or 1,243 miles) and the geosynchronous region covering a swathe 400 kilometres (249 miles) deep and 30 degrees wide around the exact geostationary altitude of 35,786 kilometres (22,236 miles). Geostationary transfer orbits used by satellites on their way to the geosynchronous region, IADC argues, should also be protected.

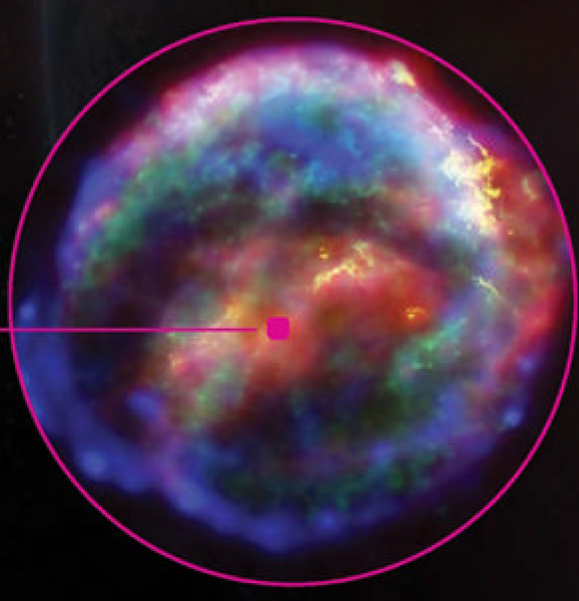


The main 250kg (551lb) fuel tank of a Delta 2 launch vehicle that landed in Texas, 1997. The vehicle survived re-entry without completely burning up in the atmosphere

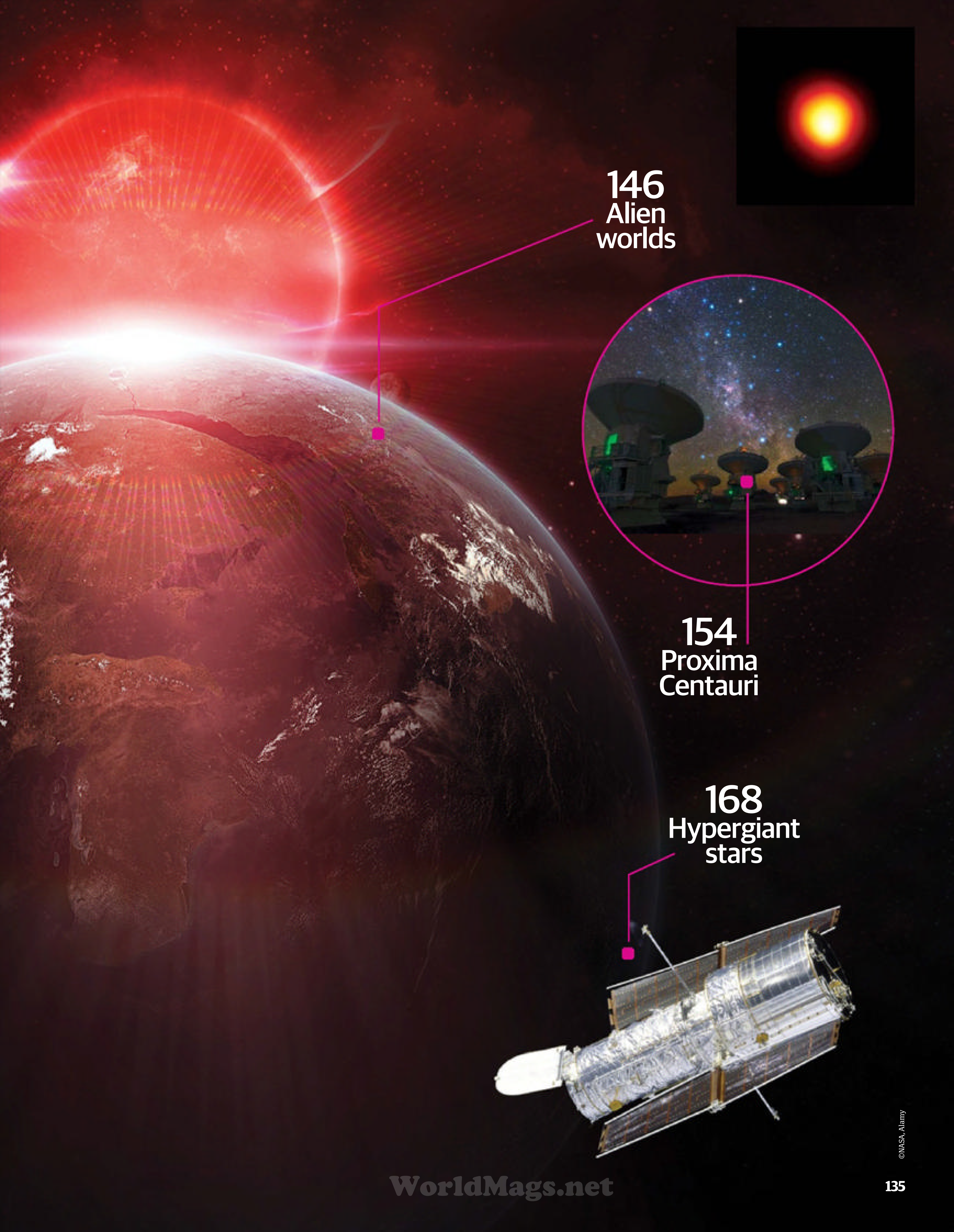
Into Deep Space

Take a look at what lies outside the comforts of the Milky Way

164
Sombrero galaxy

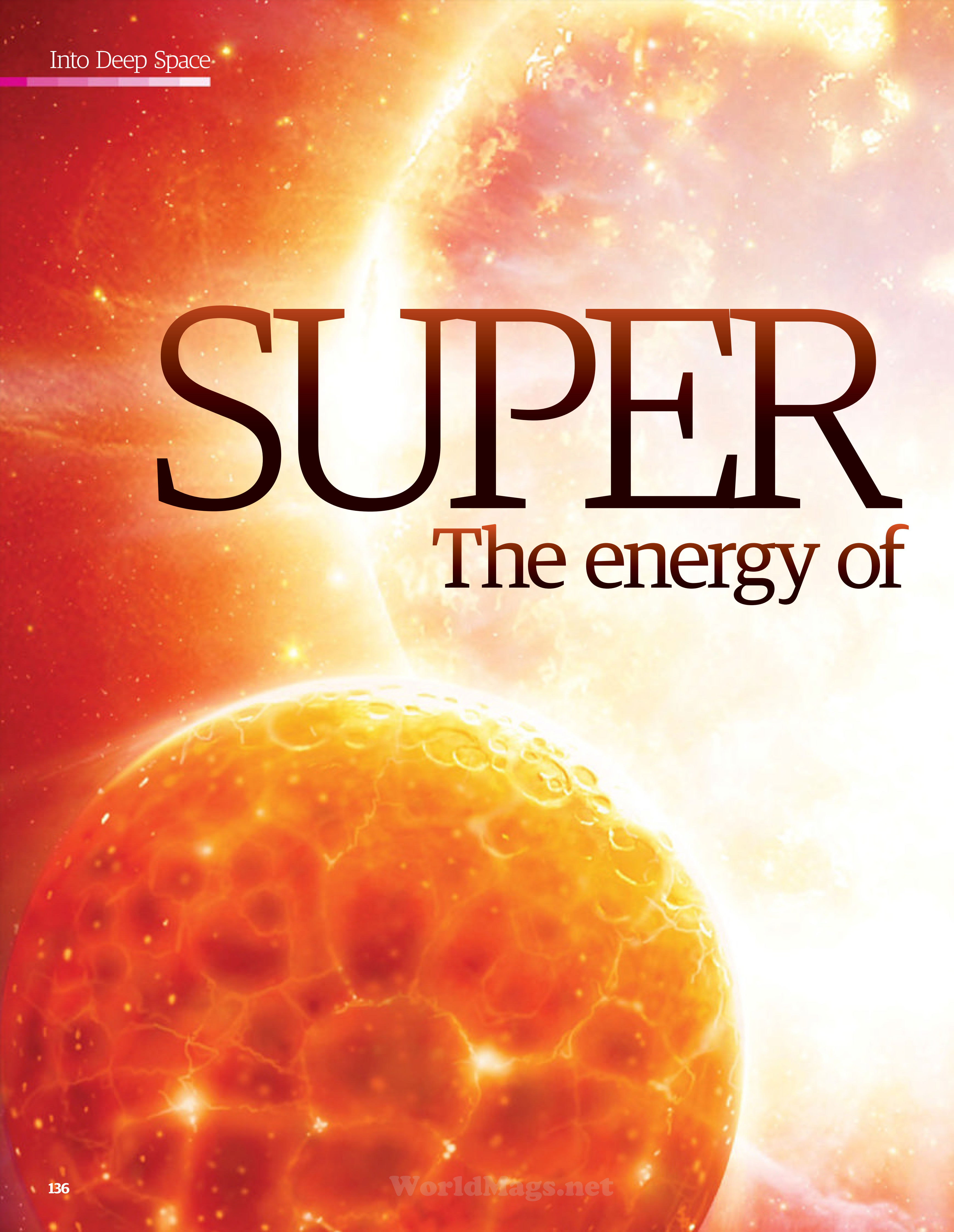


136
Supernovas



SUPER

The energy of



NOVAS
a billion suns

The massive stellar explosions capable of sending cosmic shockwaves across entire galaxies

Stars are large and volatile masses of energy, finely balanced to allow their existence to continue while also emitting large amounts of energy into their surroundings. Their very presence is one of the wonders of the universe, with these giant hot and dense balls of gas able to survive the harsh reality of space. But when the finely-tuned balance of gravity and pressure within a star is altered, something rather remarkable often happens. Try to imagine an explosion more powerful than a billion suns, and you might start to understand how stars can meet their explosive end when they go supernova.

In 185 AD, Chinese astronomers were astounded when a new star appeared in the night sky for eight months. The star appeared from nowhere and was stationary, ruling out the possibility of it being a comet. Although unknown at the time, those Chinese astronomers (and possibly Roman astronomers around the same period as well) unwittingly became the first people to record a supernova, which we know today as SN 185. In 2006, NASA's Chandra and XMM-Newton X-ray observatories imaged a remnant called RCW 86, a vast shell of gas seemingly ejected by SN 185. It might have taken 2,000 years, but we're gradually becoming able to observe and understand these massive events like never before.

When we deal with measures of time in this article, it is worth bearing in mind the limitations of the speed of light. When SN 185 was first observed in 185 AD, those Chinese astronomers were actually observing an event that happened 8,200 years prior, as SN 185 is 8,200 light years away. Of course, when the light finally reaches us we are able to observe the events in their entirety, but it is important to realise that these are cosmic occurrences that happened long in the past, from thousands of years to billions in some instances.

That doesn't take away from the scientific merit of observing them, however. They might be snapshots into the universe's past but they still hold key information into stellar life cycles and the regeneration of the cosmos. In fact, supernovas are thought to be among the most important events in the universe for a number of reasons. Before we tackle that, though, we need to understand the basics of how a supernova works.

At the heart of stars a process called fusion takes place, where light elements such as hydrogen and helium fuse together to form heavier elements, anything from carbon to iron to oxygen. The process of nuclear fusion releases a vast amount of energy in the form of many different types of radiation, including heat and visible light, both of which we directly observe and feel ourselves every day from the Sun. Stars are abundant in both hydrogen and helium, but their supplies are not endless. While it varies from star to star, eventually a star's source of fuel runs out. In most cases the predominant element left at the star's core is iron, which no star is able to fuse. What happens next is simply astounding.

Eventually, so much iron will build up that the star can no longer support its own weight. Until this point, and indeed for the majority of a star's lifetime, the force of gravity pulling the star inwards is delicately balanced by the pressure of the star's gases radiating outwards. Once the fuel is gone, however, this pressure suddenly dissipates. In just a millisecond, the core (which is now rich in iron and more massive than the Sun) collapses in on itself, shrinking in size by up to a thousand times from the size of the Earth to a ball only about 20 kilometres (12 miles) across.

Incredibly, though, the collapse is so quick that the layers of gas surrounding the core don't have time to react. Just a split second later, before these layers have even had a chance to begin collapsing as well, the now ultra-dense iron-rich core explodes with more energy than a quantity of TNT the size of Earth being instantly detonated. The energy output of a supernova is similarly astounding.

In most cases a supernova will shine as bright as 10 billion suns, and it will release 10^{44} joules, which is roughly the total output of the Sun in its entire 10 billion year lifetime. The resultant shockwave can travel at velocities approaching half the speed of light, and it will continue expanding into the surrounding interstellar space for thousands of years. The rate of expansion is such that a supernova's effects can be felt tens or even hundreds of light years away. If you think that all stars meet this same explosive end, however, you'd be wrong.

There are two main types of supernova: Type 1, or companion star supernovas, and Type II, or core collapse supernovas. The former typically occur in stars when their mass exceeds 1.4 solar masses, known as the Chandrasekhar limit, due to the accretion of matter in a binary star system with a white dwarf star, while the latter involve the collapse of stars between eight and 15 solar masses.

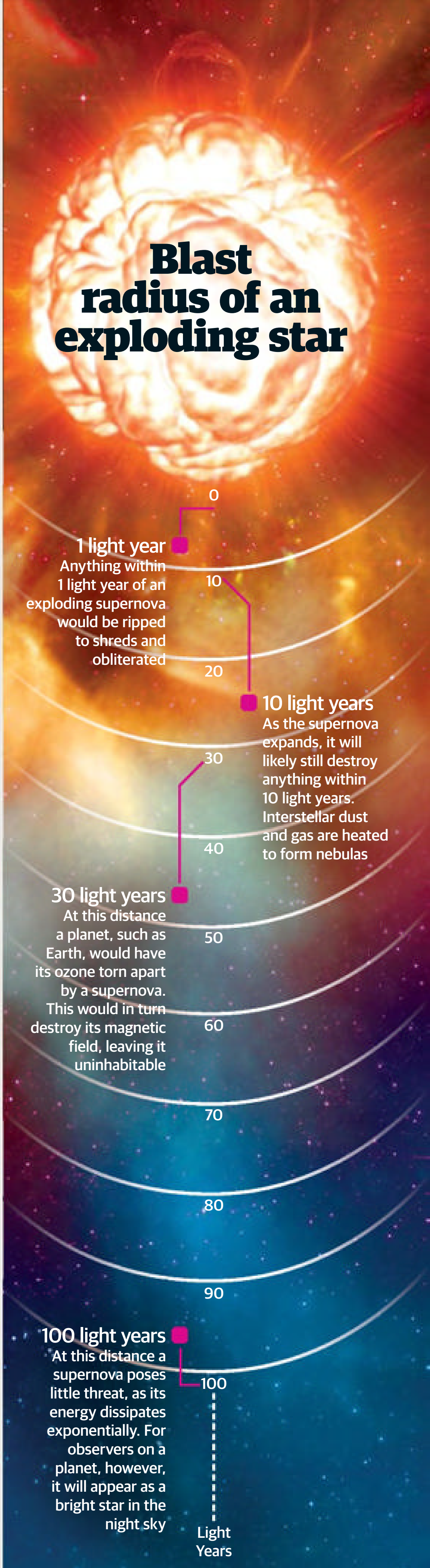
Both types are further sub-categorised to denote the particular characteristics of the supernova. The light of Type II-L supernovas steadily decreases after the explosion, whereas Type II-P supernovas emit light much more steadily. Type 1a supernovas involve a white dwarf and a larger star in a binary system, whereas Type 1b and 1c supernovas are more similar to the core collapse scenario, but they will have already lost most of their outer layers before the explosion.

One of the few supernovas to be observed was SN 2008D in the spiral galaxy NGC 2770 back in early 2008. By chance, researchers using NASA's orbiting Swift telescope noticed an increase in X-rays from the star, and immediately alerted eight other ground and space telescopes to the event. The resulting blast lasted just five minutes, but the research will surely last a lifetime. The expansion rate was estimated at 10,000 kilometres (6,000 miles) per second, although one side of the star expanded faster than the other, suggesting that the explosion was off-centred.

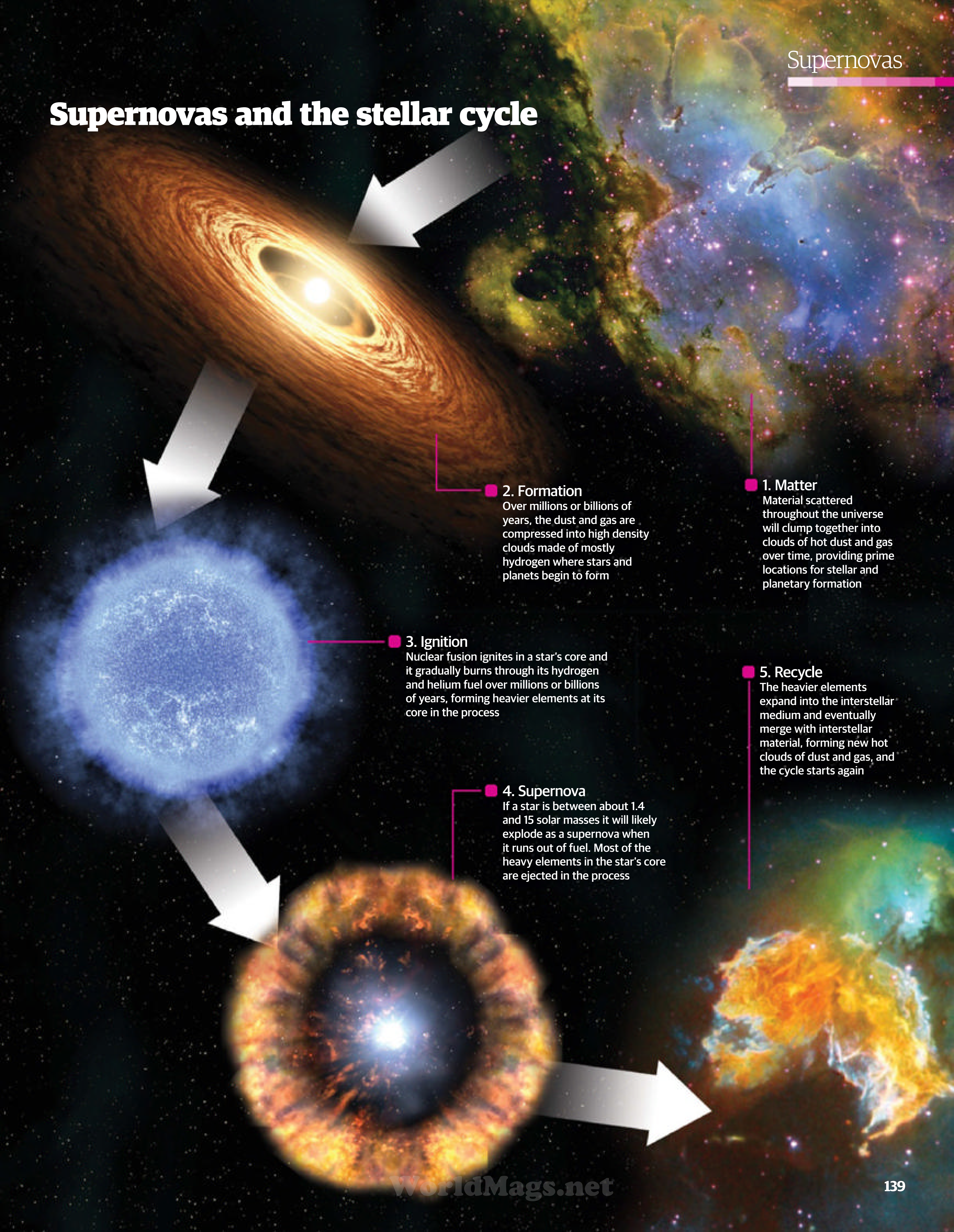
The universe is abundant in hydrogen and helium but not so much in heavier elements such as carbon and oxygen, life-essential elements without which planets like Earth could not become habitable. The only place where these heavier elements are known to be made is in the very heart of stars, where they are stored until the star explodes as a supernova and scatters them into the surrounding space. Without supernovas, these elements would remain locked away, unable to contribute to the formation of metal-rich objects like planets and asteroids. It's very likely that planetary systems, like our own Solar System, were born in this way, from a cloud of dust and gas left behind after a star went supernova.

Another important consequence of supernovas is the formation of new stars. One of the oldest stars

Supernovas often leave behind their dense cores



Supernovas and the stellar cycle



1. Matter
Material scattered throughout the universe will clump together into clouds of hot dust and gas over time, providing prime locations for stellar and planetary formation

2. Formation
Over millions or billions of years, the dust and gas are compressed into high density clouds made of mostly hydrogen where stars and planets begin to form

3. Ignition
Nuclear fusion ignites in a star's core and it gradually burns through its hydrogen and helium fuel over millions or billions of years, forming heavier elements at its core in the process

4. Supernova
If a star is between about 1.4 and 15 solar masses it will likely explode as a supernova when it runs out of fuel. Most of the heavy elements in the star's core are ejected in the process

5. Recycle
The heavier elements expand into the interstellar medium and eventually merge with interstellar material, forming new hot clouds of dust and gas, and the cycle starts again

that we know of is HE 1523-0901, a red giant star 7,500 light years from Earth. It was thought to have formed about 13.2 billion years ago, 500 million years after the estimated beginning of the universe. Clearly this means that most stars that we know of were formed after the Big Bang, in some cases (such as our own Sun) many billions of years after. The only way new stars could have been born was if older stars that survived from the birth of the universe eventually went supernova, releasing their various elements and eventually leading the way to the formation of new stars.

The final major contribution of supernovas to the universe is the continued addition of heavy elements to the interstellar medium. The gradual growth in abundance of these heavier elements, ones that were only found in traces before, has had an odd effect on some stars. Those like our own Sun undergo a somewhat different fusion process to those stars born nearer the start of the universe, as the former are moderated more by the presence of carbon. It is likely that future stars will continue to be altered by the presence of more heavy elements, further altering the fusion process within stars.

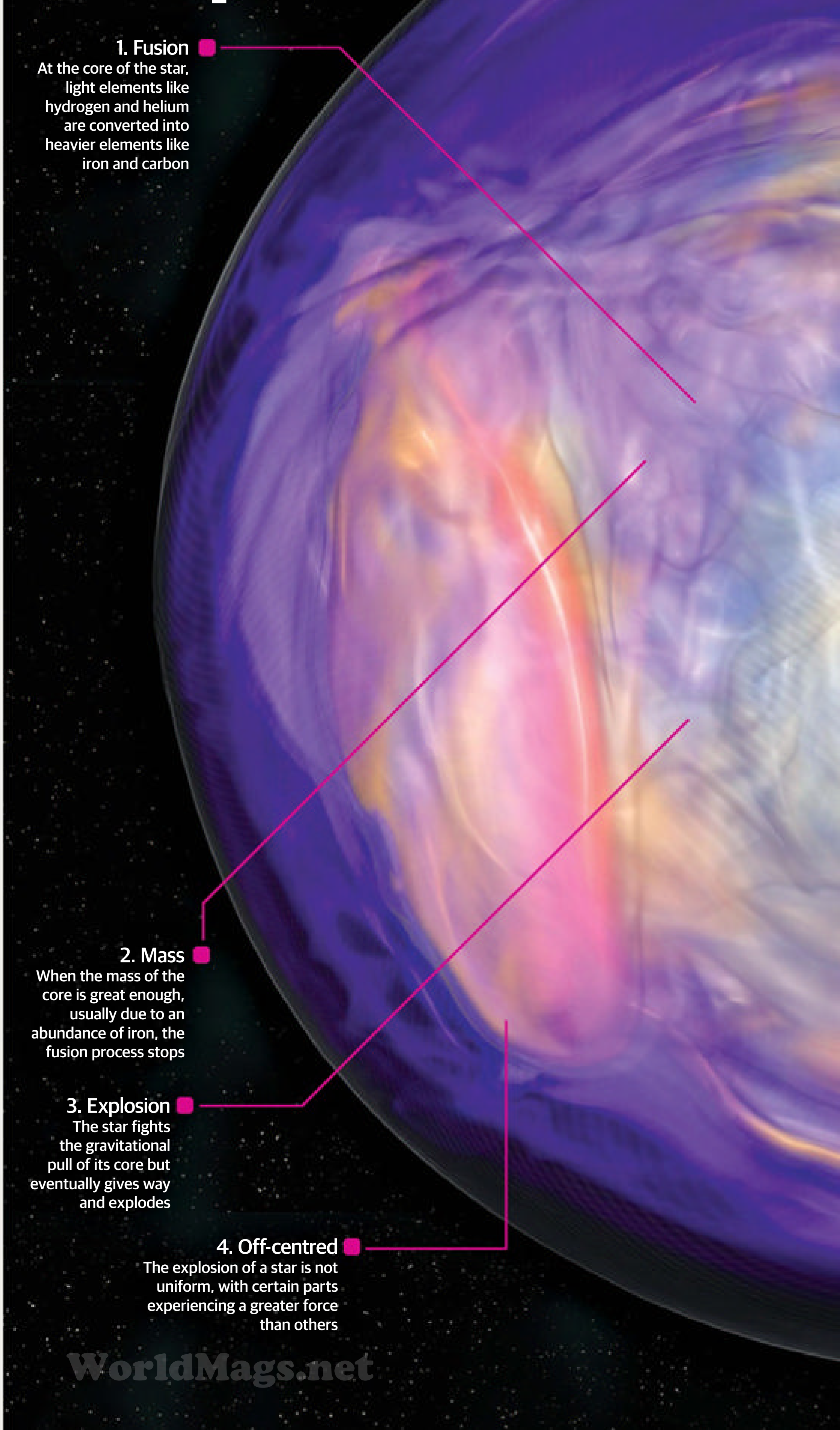
So, it's safe to say that supernovas are really quite important, but how do we know so much about them? After all, we've only observed very few, instead normally catching only the aftermath or the resultant remnant. Well, fortunately by observing the aftermath we're able to discern a lot about the explosion itself. For one thing, most Type 1a supernovas seem to undergo very similar final moments. If we see one explode we are able to calculate how far away it is thanks to something known as the "standard candle" method, where all Type 1a explosions explode with pretty much the same magnitude. In addition, using spectroscopy, we can analyse the resultant remnant and, by observing its size and composition, we can work out what the original star might have been like.

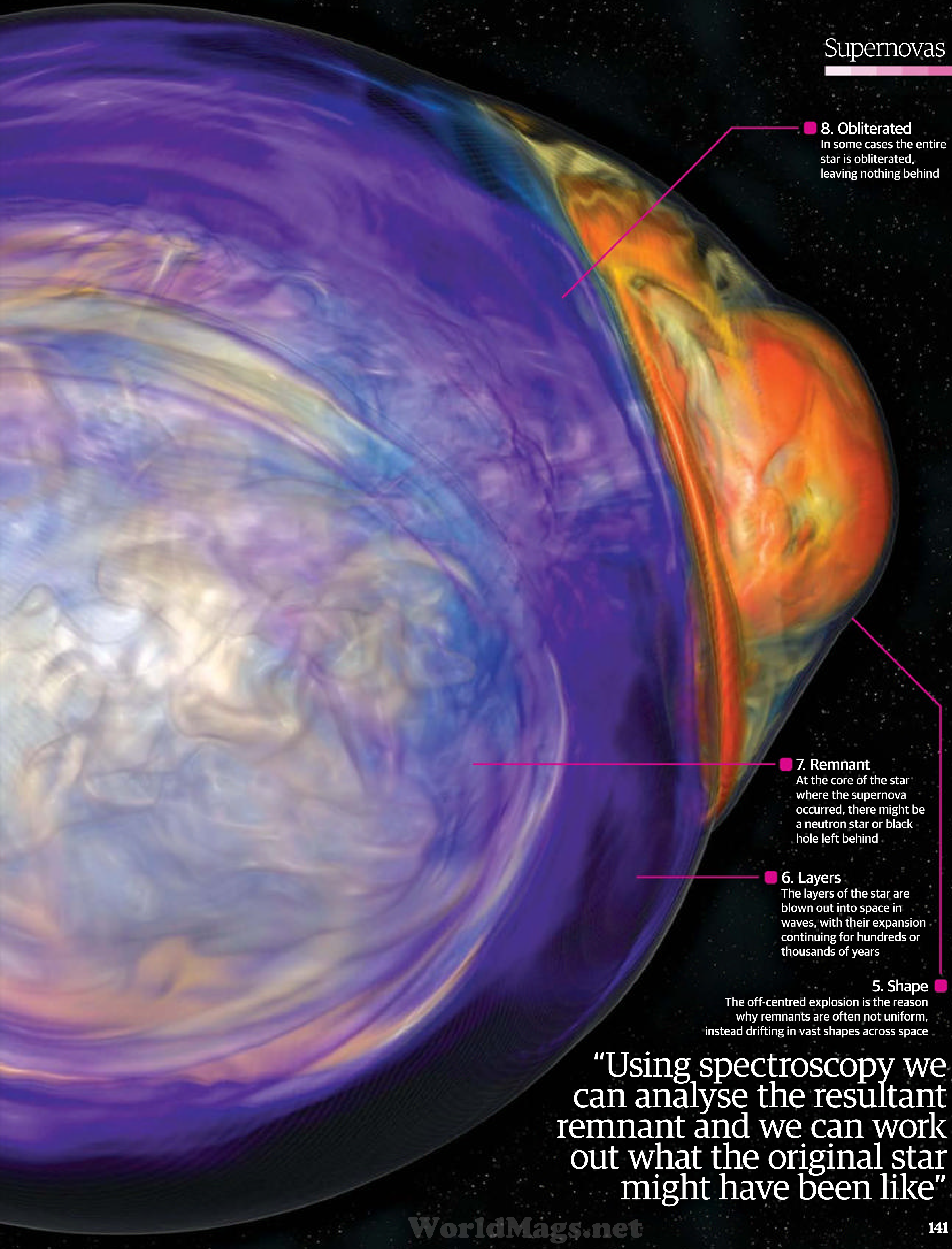
Supernovas will continue to be one of the most fascinating and exhilarating events in the universe, providing us with a view into stellar formation and the death of stars. It is thanks to these events that we know so much about the inner composition of stars, and by continuing to study them we will unearth more secrets of the universe.

What is a remnant?

A supernova remnant is the expansion of the blast wave from the supernova as it moves through space, pushing material out along with it that we can observe in different wavelengths from Earth. The expansion rate of a remnant can be up to several thousand kilometres per second, approaching 1% the speed of light, and it may continue for hundreds or thousands of years. Many nebulas we can see from earth are the result of the expansion of supernova remnants, and they can often measure several hundred light years across.

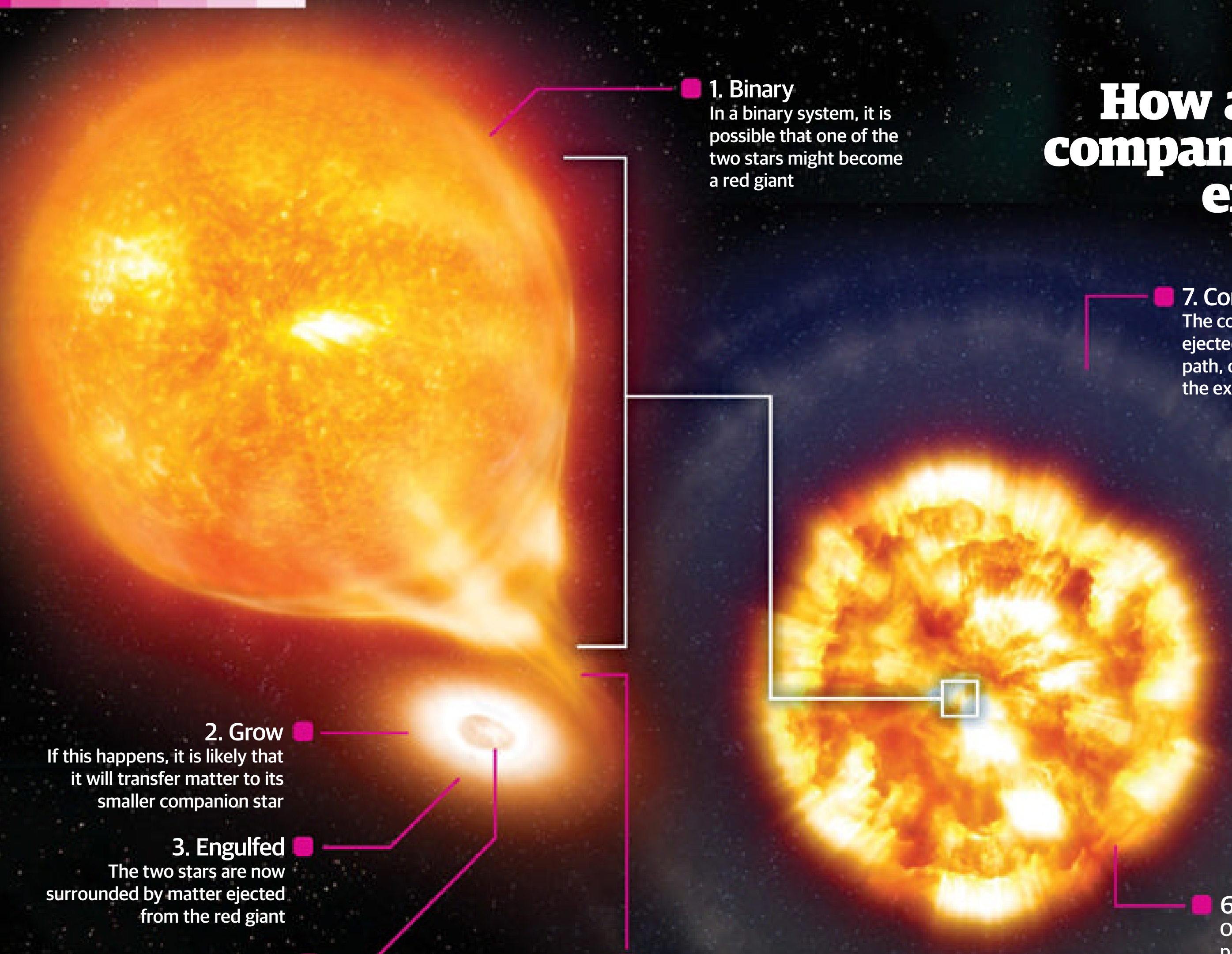
What happens when a star explodes?





"Using spectroscopy we can analyse the resultant remnant and we can work out what the original star might have been like"

How a Type I companion star explodes



1. Binary
In a binary system, it is possible that one of the two stars might become a red giant

2. Grow
If this happens, it is likely that it will transfer matter to its smaller companion star

3. Engulfed
The two stars are now surrounded by matter ejected from the red giant

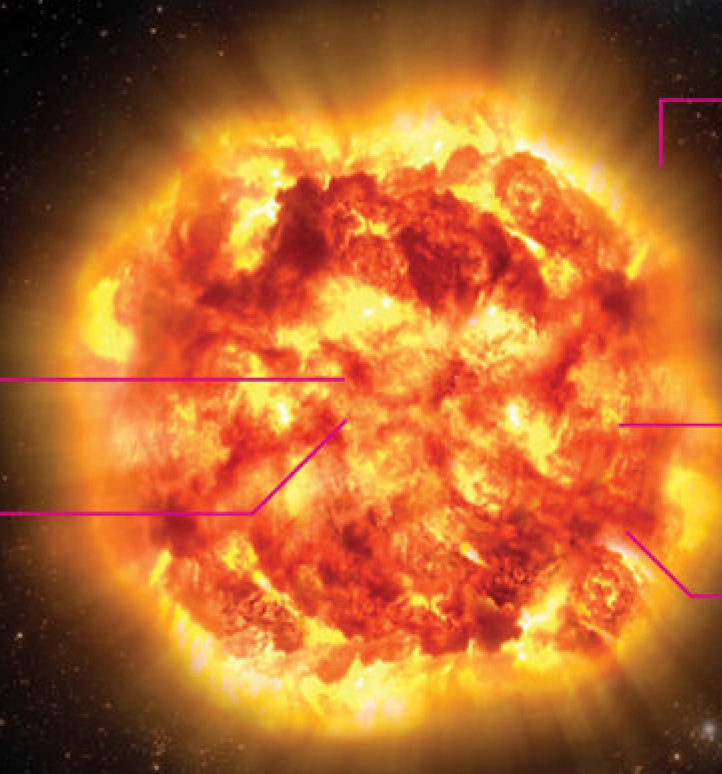
4. Collapse
The red giant star now collapses, leaving only its core behind as a white dwarf

5. Transfer
The companion star now transfers matter to the white dwarf, increasing its mass

6. Explosion
Once the white dwarf passes 1.4 solar masses, known as the Chandrasekhar limit, it can no longer support itself and explodes

7. Companion
The companion star may be ejected out of the supernova's path, or it may be engulfed by the explosion and destroyed

What happens in a Type II core collapse



1. Core
A star's iron core collapses under the force of gravity as it runs out of fuel

2. Density
When the density of the core exceeds that of the surrounding matter, the core starts sending out waves of pressure

3. Shock waves
The pressure waves rebound off material falling towards the core, sending shockwaves back into the centre of the star

4. Energy
At first, the waves are unable to overcome the force of the outgoing pressure waves and thus cannot reach the surface of the core

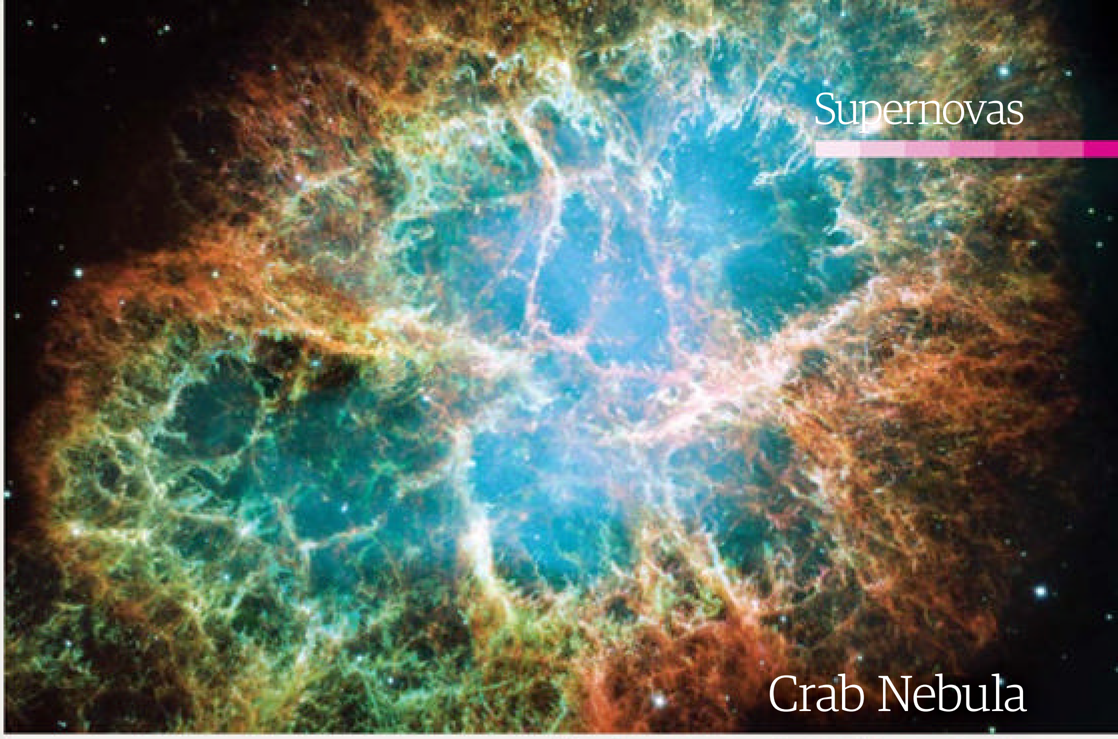
5. Explosion
Eventually, the build-up of shockwaves overcomes the pressure waves, and the surface of the core is impacted and, subsequently, explodes

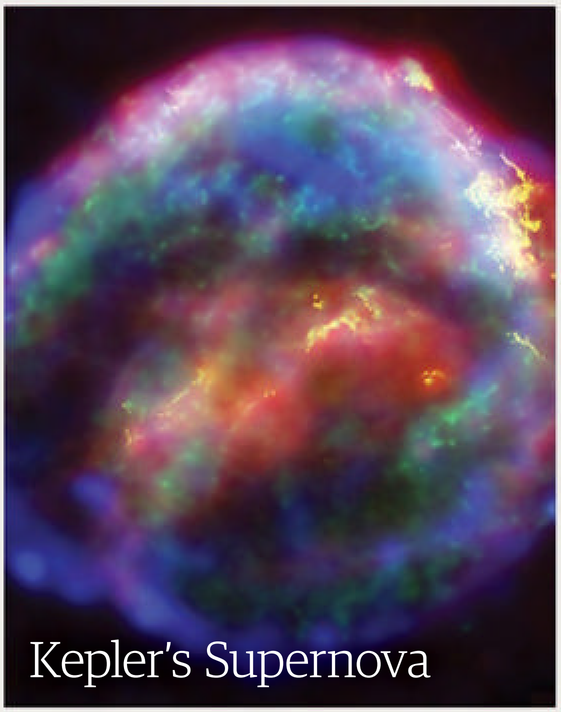
Most spectacular supernovas

Crab Nebula
Exploded: 7,500 years ago
Distance: 6,500 light years
This famous supernova remnant has a rapidly rotating star known as the Crab Pulsar at its centre, left behind after the original star exploded. This nebula is now 11 light years across but is still expanding at a rate of 1,500 km (930 miles) per second, 0.5% the speed of light. It is part of the Perseus Arm of the Milky Way Galaxy and the nebula is also referred to as Messier 1 or M1, being the first Messier Object catalogued in 1758. The explosion of the supernova that created this nebula, SN 1054, was recorded around the world in 1054 AD.

Kepler's Supernova
Exploded: 24,000 years ago
Distance: 20,000 light years
Observed by astronomer Johannes Kepler in October 1604, hence the name, Kepler's Supernova (SN 1604) is the most recent stellar explosion that was visible to the naked eye on Earth, although evidence exists for a Milky Way supernova whose signal would have reached earth around 1868, but was not visible to the unaided human eye. Kepler's Supernova was brighter in the night sky for three weeks than any other star or planet, except for the Sun and Venus, and could even be seen during the day.

RCW 86
Exploded: 11,000 years ago
Distance: 9,100 light years
This supernova remnant is thought to be that left behind after star SN 185 blew up in 185 AD. It was recorded by Chinese astronomers and remained visible for some eight weeks. Recent X-ray studies show a good match for this estimated age. As such, RCW 86 is the oldest recorded supernova, and was thought to be a companion star supernova. The remnant is bigger than scientists would expect from such a supernova, suggesting the initial dwarf star created a 'cavity' in space before it exploded into which ejected material could quickly traverse.

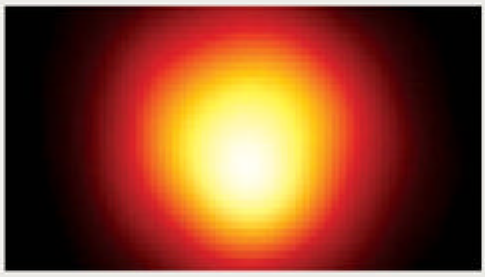

Crab Nebula


Kepler's Supernova


RCW 86

Coming soon to a galaxy near you...

IK Pegasi
Will explode: 5 million years from now
Distance: 150 light years
IK Pegasi A is expected to evolve into a red giant, which will transfer matter to the smaller IK Pegasi B white dwarf star and cause it to explode in a Type 1a supernova. IK Pegasi is moving away, so while it is currently the closest star to us that can go supernova, when it does in a few million years it will no longer be.



Betelgeuse
Will explode: 0 to 1 million years from now
Distance: 640 light years
Currently in the later stages of its life, it is expected to explode as a Type II supernova within the next million years, although it could explode at any minute. The star is a red supergiant and is less than ten million years old, a miniscule amount in astronomical terms, and thus it has passed through its life rapidly.

Antares
Will explode: 0 to 1 million years from now
Distance: 550 light years
The red supergiant Antares has a companion star, Antares B, that is thought will contribute to a Type 1a supernova event in the coming years. However, the exact timing of the supernova is unknown. Antares is more than 880 times bigger than our Sun and thus the explosion is expected to be quite an event.

Behemoth galaxy

At the heart of the giant Perseus cluster lies a monster of a galaxy

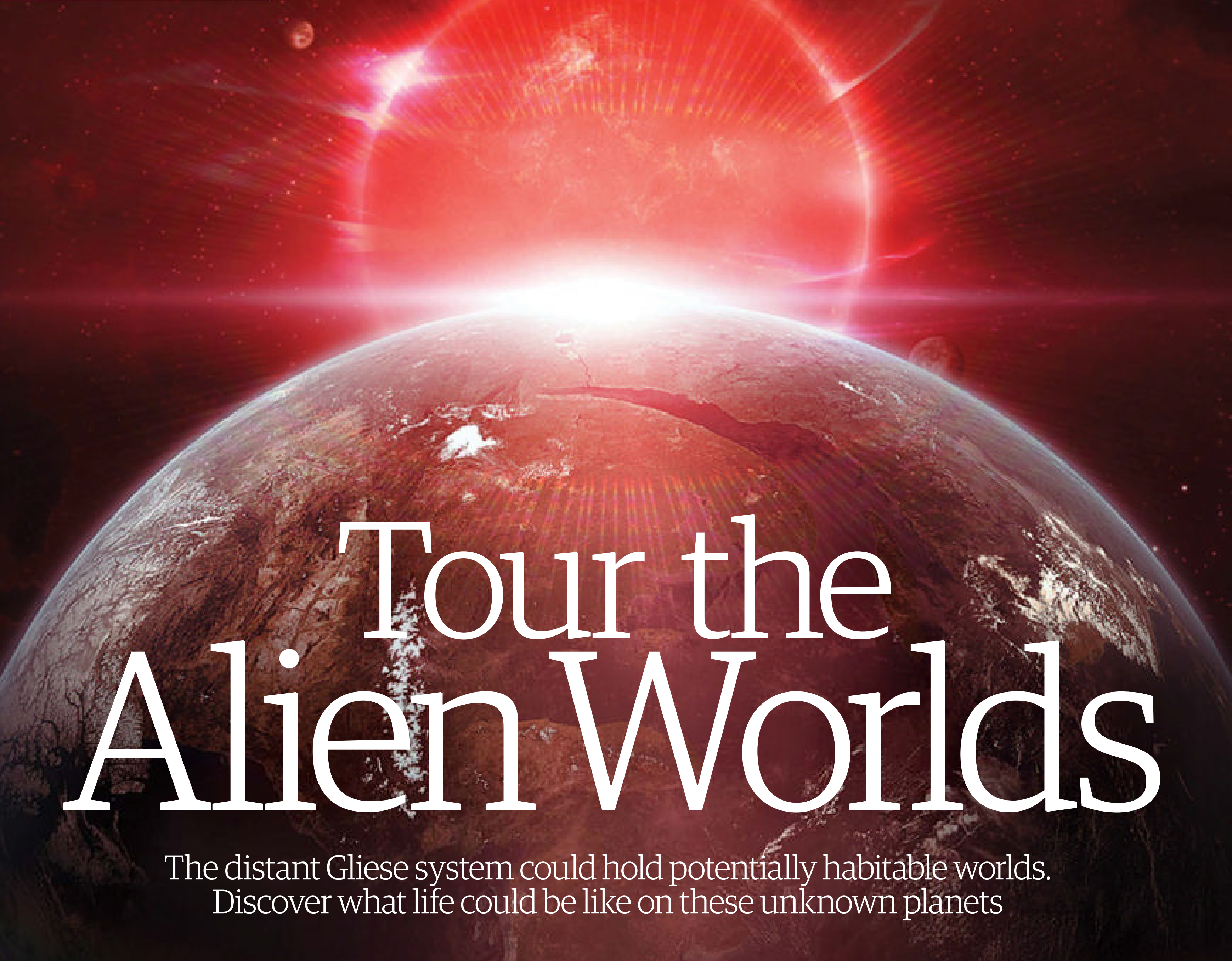
It seems appropriate that one of the most massive known objects in the universe, the Perseus galactic cluster, should also be home to a particularly huge galaxy at its centre. The giant elliptical NGC 1275 is 230 million light years away in the constellation of Perseus and actually consists of two galaxies – one a huge elliptical and the other a small spiral – in what's known as a high-velocity system.

These galaxies seem set to collide and are moving towards each other at 3,000 kilometres (1,864 miles) per second. This Hubble Space Telescope image shows filaments of cool, mainly hydrogen gas surrounded by gas measuring up to 55 million degrees Celsius (100 million degrees Fahrenheit) in the cluster, which emits strong X-rays.

The Perseus cluster has recently come under the spotlight of astronomers because it's the source of a particular X-ray signal that couldn't have come from ordinary matter. It's thought that an exotic particle called a sterile neutrino, which is related to dark matter, could be responsible. Study of the Perseus cluster, and other massive objects in the universe like it, is giving scientists a better idea of the nature of dark matter.

Behemoth galaxy

Filaments feed out of the giant elliptical galaxy NGC 1275 in searing-hot, X-ray-emitting gas in the Perseus cluster



Tour the Alien Worlds

The distant Gliese system could hold potentially habitable worlds. Discover what life could be like on these unknown planets

Only 20 light years away from Earth lies a world that, if it were confirmed, looks pretty similar to our own. Gliese 581 g (as it is known by astronomers) is only three to four times the mass of Earth. It's tricky to say if it exists for sure because of the different measurement techniques used by various astronomers, but the possibilities are tantalising.

Astronomers using the WM Keck Observatory in Hawaii spotted evidence of the planet in 2010. It's thought to be a rocky planet, just like Earth, it probably has an atmosphere and, most importantly, it's in the 'Goldilocks Zone' around a star. This is the zone where temperatures are not too hot and not too cold but 'just right' to support life.

"This is a really exciting system," says Lisa Kaltenegger, an astrophysicist at Harvard University. "If it had water, it would be actually liquid on the surface. It's the first time we've been able to peer across space and detect a possible planet that would be similar to our own."

Even if 581 g turns out to be a false finding, there is even hope that another planet in the same system - 581 d - could support life, if it had a layer of carbon dioxide protecting water on its surface. This makes the entire star's solar system a fascinating target for astronomers.

Planet G of the Gliese 581 system is one of several planets orbiting the red dwarf star. Gliese 581 is a small star only 20 light years away from Earth. Because the star is a red dwarf, it gives off less heat and light than our Sun, which means its Goldilocks Zone is much closer to the star than the one in which the Earth resides in our Solar System.

Gliese 581's known planets hug the star very closely and the furthest planet from the star, Gliese 581 f, orbits at about the same distance as the planet Venus is from our Sun. (It should be emphasised that Gliese 581 f is not recognised by all astronomers yet.) The rest of Gliese 581's planets are closer to the star than Mercury's orbit from the Sun.

According to Kaltenegger, who splits her research time between Harvard and Germany's famous Max Planck Institute for Astronomy, Gliese 581 has two potential planets that lie around the habitable area. Planet G is the best candidate, if it exists, and Planet D lies just on the outer edge of the zone. But Kaltenegger says it's best not to get too excited yet. "We have great targets, but we don't know if (they) can support life," she says, adding that the next step is to find a way to use telescopes to peer closer at these planets' atmospheres.

Kaltenegger is keen to note that not everyone is in agreement about Planet G's existence. Although announced with great fanfare by NASA and related astronomers in 2010, the way the astronomers detected the planet has not been reliably replicated yet, at least as far as Kaltenegger sees it. Astronomers at the University of

> "It's the first time we've been able to peer across space and detect a possible planet that would be similar to our own"
> **Lisa Kaltenegger, astrophysicist at Harvard University**

California, Santa Cruz used 11 years of telescope observations at Keck to find Gliese 581 g, using a spectrometer that watched over its parent star. The spectrometer was used to measure the star's radial velocity, or its movement relative to Earth's line of sight. If a star has planets that are large enough and close enough, the planets tug at the star's gravity ever so slightly. With multiple planets orbiting the star, the star begins to wobble.

Planet hunters have become so sophisticated in their techniques that they can take a star's wobble and infer how many planets are orbiting it, as well as the masses of those planets.

"Keck's long-term observations of the wobble of nearby stars enabled the detection of this multi-planetary system," stated Mario Perez, a programme scientist at the Keck Observatory, in the news release concerning Planet G's discovery.

However, a team from Geneva (led by Francesco Pepe) analysed over six years of data concerning Gliese 581 using a spectrometer at La Silla Telescope in Chile.

Also in 2010, they announced at an exoplanet conference in Italy that they had not found any evidence of Gliese 581 g. That said, the precision of the instrument is not sharp enough to definitively rule Gliese 581 g out.

Subsequent teams of astronomers have been arguing back and forth for years now whether 581 g is actually there, or if the wobble detected around the star needs to have a new model made to explain it. It will take more observations of the star before anyone can say for sure what lies within that system and a definitive answer may not come for years or even decades.

The planet 581 d lies slightly further from the star than 581 g. It's also a bit larger than our world at between five and seven Earth masses. In a science paper posted on Arxiv, Kaltenegger's team calls it a "potentially habitable rocky Super-Earth".

Also, it's a little on the cold side when it comes to habitability, but some astronomers believe a thick layer of carbon dioxide in the atmosphere could shield 581 d from the cold. Of course, that's assuming the planet has an Earth-like composition, which is not a guarantee.

The theory, as Kaltenegger explains it, is carbon dioxide gets emitted from volcanoes on 581 d's surface. In the early days of the planet's formation, rain would wash the carbon dioxide out of the atmosphere so it couldn't accumulate. But as the planet cooled, that rain would turn into snow. Snow doesn't have the same power to wash carbon dioxide away, so the gas would accumulate in the atmosphere.

"It builds up in the atmosphere, increases your greenhouse effect, and warms until you have water," Kaltenegger says. This makes it easier to believe that life would exist there.

Even if planets 581 g and 581 d were vegetated, though, it would look a lot different from Earth. The cool light from Gliese 581 would barely be enough for plants to photosynthesise, so the plants would not be green like you would see here on Earth. The colour would take too much energy. Additionally, the light would look different than what we are used to on Earth, as a red dwarf mostly gives off its energy in red light.

In 2012, Australian astronomers – who are involved in the search for extraterrestrial life – trained their cosmic ears at Gliese 581. They linked together three radio telescopes in Australia in an attempt to hear radio signals coming from the system.

The astronomers didn't hear anything, but that's not to say that life is absent from the system. Gliese 581 d and 581 g are both in or within the habitable zones, and it will take many years of future study to learn more about their climatic conditions.

In the meantime, Gliese 581's system provides plenty for astronomers to study. There are up to six planets orbiting the star, each with a unique environment worth closer study.

While 581 f and 581 g are not universally accepted, there are four others that are receiving further attention from astronomers.

581 e is the closest to the star and would appear as a big Mercury if you were standing on the surface. It's about double the mass of Earth.

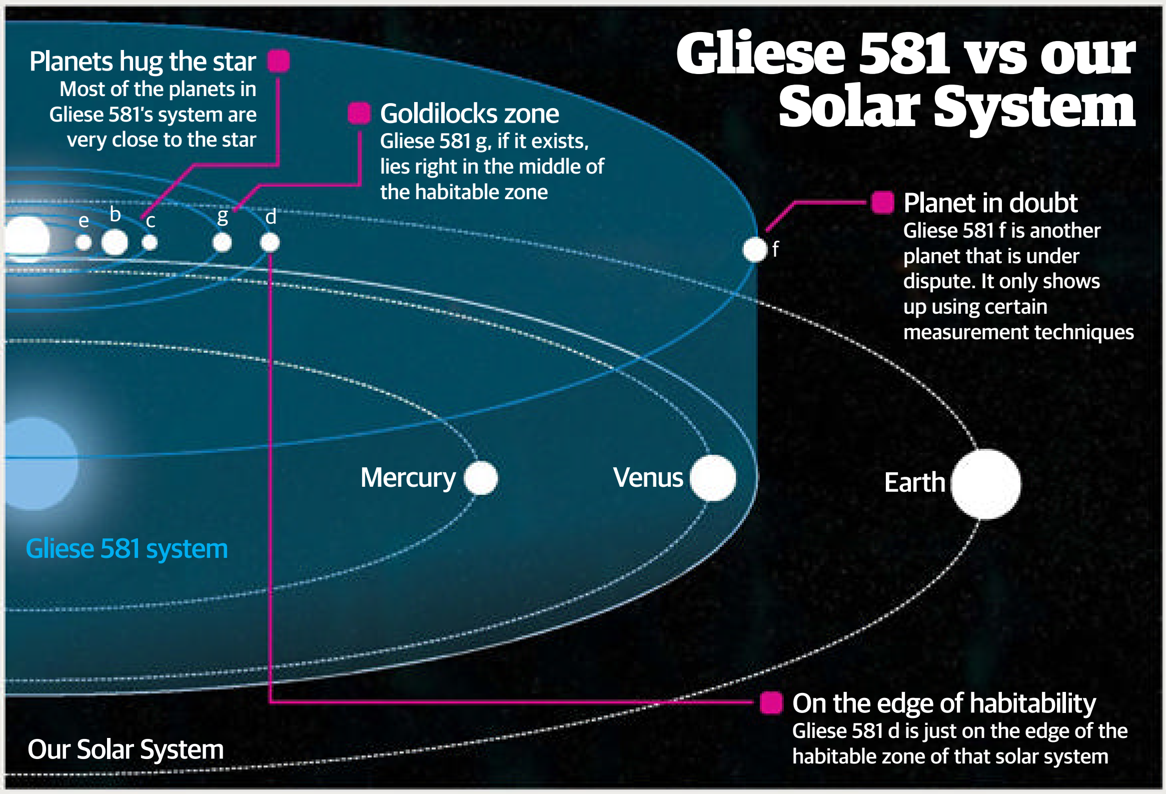
Next out is 581 b, which would be a gas planet – at 15.6 Earth masses – that is approaching the size of Jupiter.

Third in the system, and before 581 g and 581 d, is 581 c. Planet C, more than five times Earth's mass, would actually look a lot like Venus, in that any water would have evaporated from the surface and it would probably be covered in a thick atmosphere if it had any available to it.

Kaltenegger says we are just at the beginning of understanding the Gliese 581 system. "Planets are so hard to find because they look tiny near the star," she explains. "(What's) exciting is we're finding more and more planets with this simple wobble method… we can even find the small ones that don't have much mass or are not very big."

Surely as telescopic observations and computer technology continue to improve, we'll have the opportunity to spot more candidates for supporting life like Gliese 581 d or 581 g. We'll be able to more precisely predict how planets move about their stars, and also be able to infer the composition of their atmospheres.

Learning more about the way other solar systems formed brings us to a better understanding of what happened here on Earth. Gliese 581's system, even though it is 20 light years away from us, will therefore teach us more about our own home.



On the surface – an expert's view

We asked expert Lisa Kaltenegger to take an educated guess at what conditions might be like on the planets surrounding Gliese 581

Gliese 581 e

"The Gliese 581 system is intriguing because it hosts planets that could be like big Earths and also planets that are so different from the ones we know in our Solar System," said Kaltenegger. Gliese 581 e is estimated to have a mass about double that of Earth, and "at this mass we can speculate that it could resemble a hot super-Mercury on a three-day orbit." It is extremely close to the Gliese star and therefore likely to be very hot.

Gliese 581 b

"Without more information we can only speculate what these planets could be like - until we get a bigger telescope that can explore their atmospheres and tell us what they are like," said Kaltenegger. This is especially true for Gliese 581 b. "All of the planets in the Gliese system are heavier than Earth." The heaviest of those is Gliese 581 b at almost 16 Earth masses, which could be a "hot mini-Neptune" or a Venus-like world.

“The Gliese 581 system is intriguing because it hosts planets that could be like big Earths”

Gliese 581 c

The “heavy super-Venus” Gliese 581 c would likely resemble the hottest planet in our Solar System, with a mass at least 5.6 times that of Earth, making it a so-called “super-Earth”, although “the jury is still out on how rocky any of these planets can be.” Once thought to be a prime candidate for habitability, the current train of thought is that Gliese 581 c would be inhospitable to life as we know it due to its hot environment.

Gliese 581 d

This is probably the most Earth-like of these planets, found in the system’s habitable zone. “If Gliese 581 d is really a rocky planet that could have developed life,” says Kaltenegger, “then such life would be used to a red sun in its sky and may have very different dark vegetation – if it developed at all. It would be a heavy, cooler, super-Earth with about double Earth’s gravity, a workout for us were we ever to set foot on the surface.”

Deepest ever view of the universe

Hubble scientists have recorded the history of galaxies in this one image, from soon after the first galaxies were formed to their huge contemporaries

You are looking at one of the most extraordinary views of the universe ever created. It's called the eXtreme Deep Field or XDF and was assembled by combining ten years of NASA Hubble Space Telescope photographs taken of a patch of sky at the centre of the original Hubble Ultra Deep Field. This was an image of a small area of space in the constellation Fornax, created using Hubble Space Telescope data from 2003 and 2004. The new full-colour XDF image shown here uses the infra-red spectrum to reach much fainter galaxies, enabling new studies of the earliest galaxies in the universe. This has been achieved by incorporating well over 2,000 separate exposures from Hubble's two main cameras – the Advanced Camera for Surveys, which has been operational since 2002, and the Wide Field Camera 3, which was installed during the very last service of the telescope performed in 2009.

The image represents a valuable astronomical tool which will be used by scientists for many years, showing more than 5,000 galaxies, among which is a candidate for the most distant galaxy yet discovered. Should this be confirmed, the galaxy known as UDFj-39546284 is being seen just 460 million years after the Big Bang. In fact, most of the galaxies visible in the XDF are seen when they are in their infancy, often colliding and merging together and these images can be followed up by the other, more powerful telescopes of the future such as the James Webb Space Telescope, which should be operational by 2018 and offer even deeper views into the history of the universe.

This image was created from over 2,000 separate exposures captured by the Hubble Space Telescope

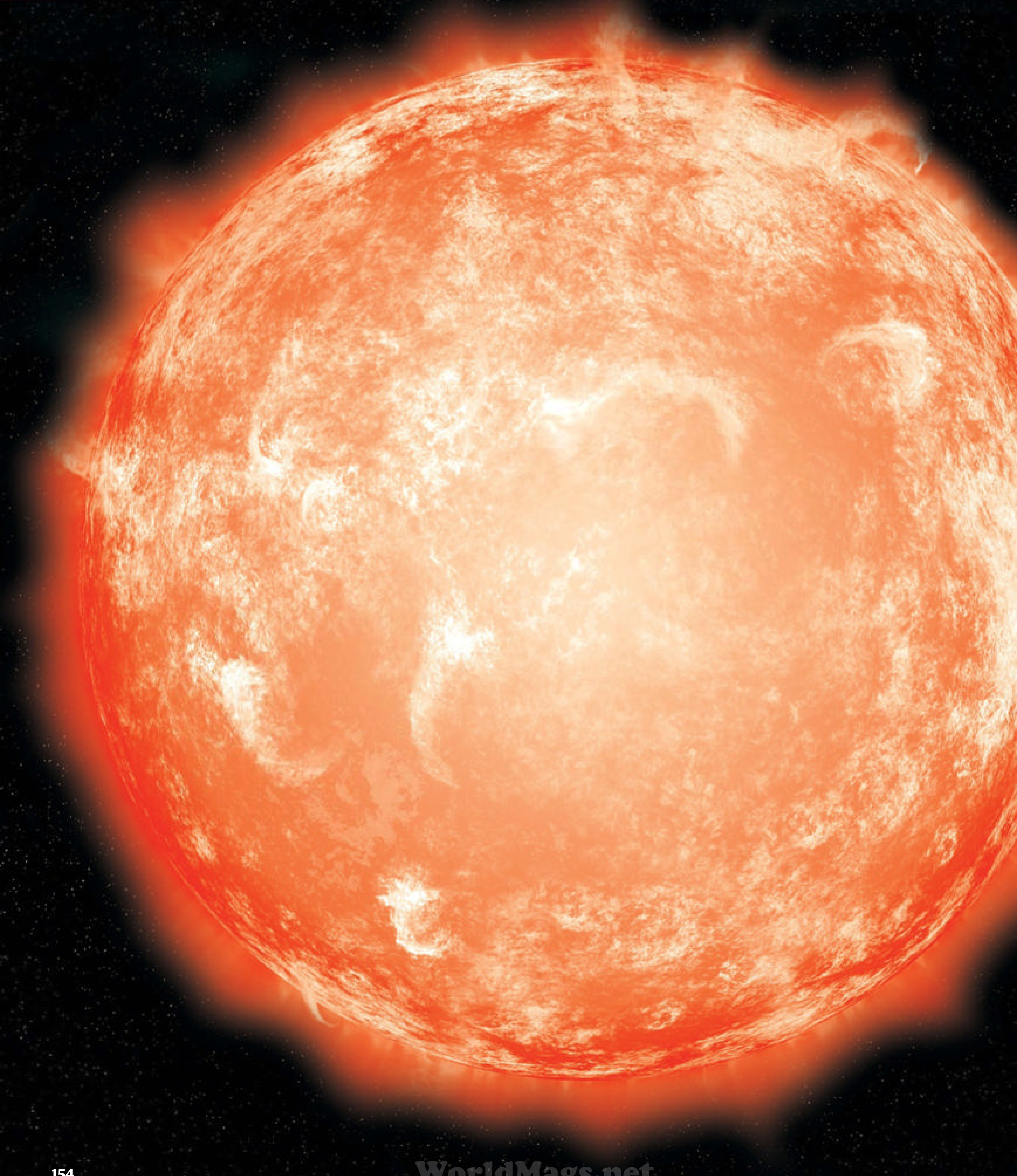
Bubble Nebula

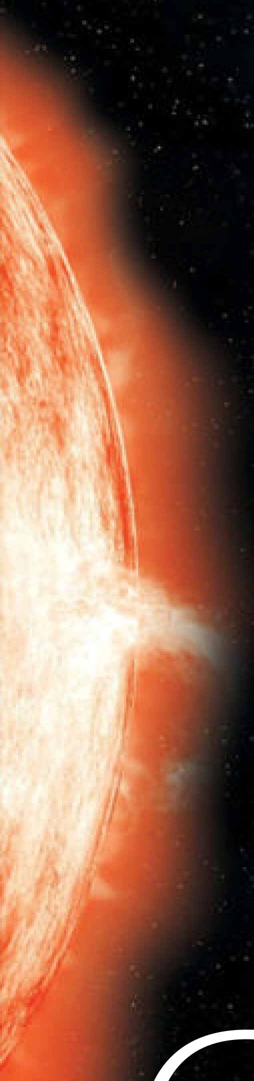
What's behind this interstellar phenomenon floating in the far reaches of space?

11,000 light years away in the Cassiopeia constellation can be found this fascinating nebula that at first glance bears resemblance to a bubble. Also known as NGC 7635, the ten-light-year-wide Bubble Nebula is an emission nebula that was formed from a young and hot star at its centre.

It was first discovered in 1787 by William Herschel, and since then it has been the subject of detailed observations. Near the centre of the bubble can be seen the bright star BD+60°2522, several hundred thousand times more luminous and nearly 50 times more massive than the Sun. This star blasted out intense radiation and a fierce stellar wind, which in turn interacted with denser material in a surrounding molecular cloud and formed the Bubble Nebula.

The nebula itself is one of three shells of gas originating from BD+60°2522. This star also ionises the shell by continuously emitting energetic radiation, which causes it to shine. Aside from the interesting shells that glow from the interaction with its central star, some wisps near the bottom right of the image are the remnants of a supernova explosion thousands of years old.





All About... PROXIMA CENTAURI

This tiny star has captured our interest in a big way as it's the closest one to Earth after our own Sun

Red dwarfs are the most common type of star in our galaxy, but they're impossible to observe from the Earth with the naked eye because they're the dimmest stars. They're also very small and relatively cool due to their low mass. The red dwarf Proxima Centauri is among the smallest and dimmest, but it has the special significance of being the closest star to us other than the Sun.

Proxima Centauri is approximately 4.24 light years (268,000 AU) away, located in the Centaurus constellation. The star is estimated to remain the closest star to ours for another 30,000 years or so, at which point the star Ross 248 in the Andromeda constellation will come closer (it's currently about 10.3 light years away).

Proxima Centauri is located about 15,000 AU from the next-closest star, the binary system Alpha Centauri. This relative closeness is how Proxima came to be discovered. In 1915, Scottish-South African astronomer Robert Innes observed a star that had the same proper motion - the apparent change of a star's position on the celestial sphere - as Alpha Centauri, which had been first observed in 1689. Depending on who you ask, Proxima is either a companion to Alpha Centauri or a third star in the system.

Since its discovery, Proxima has been closely observed. Because it's a red dwarf, it will be around for much longer than our Sun - at least four trillion more years - thanks to its slow consumption of fuel. And unlike the Sun, Proxima will completely use up its hydrogen during the fusion process. Satellite X-ray telescopes have provided crucial information about its activities. The Einstein Observatory, an X-ray telescope that orbited the Earth from 1978 to 1982, took the first X-ray images of the star and recorded a solar flare - flashes of brightness and heat caused by magnetic activity. This confirmed astronomer Howard Shapley's announcement in 1951 that Proxima Centauri was a flare star. The European Space Agency's European X-ray Observatory Satellite (EXOSAT), German ROSAT, and the Japan Aerospace Exploration Agency's Advanced Satellite for Cosmology and Astrophysics (ASCA) have all observed numerous solar flares on Proxima.

Land-based telescopes have also given us data about Proxima. Operated by the European Southern Observatory, the Very Large Telescope (VLT) helped to determine Proxima's distance and size. The star has a mass about one-eighth that of the Sun's, but it's about 40 times denser. Proxima's corona, or plasma 'atmosphere' extending into space beyond the surface, can actually be hotter than that of the Sun - 3.5 million Kelvin as opposed to 2 million Kelvin. On average, its overall temperature is about 3,000 Kelvin. Observations of Proxima's chromosphere indicate that it has a rotation period of about 31 days.

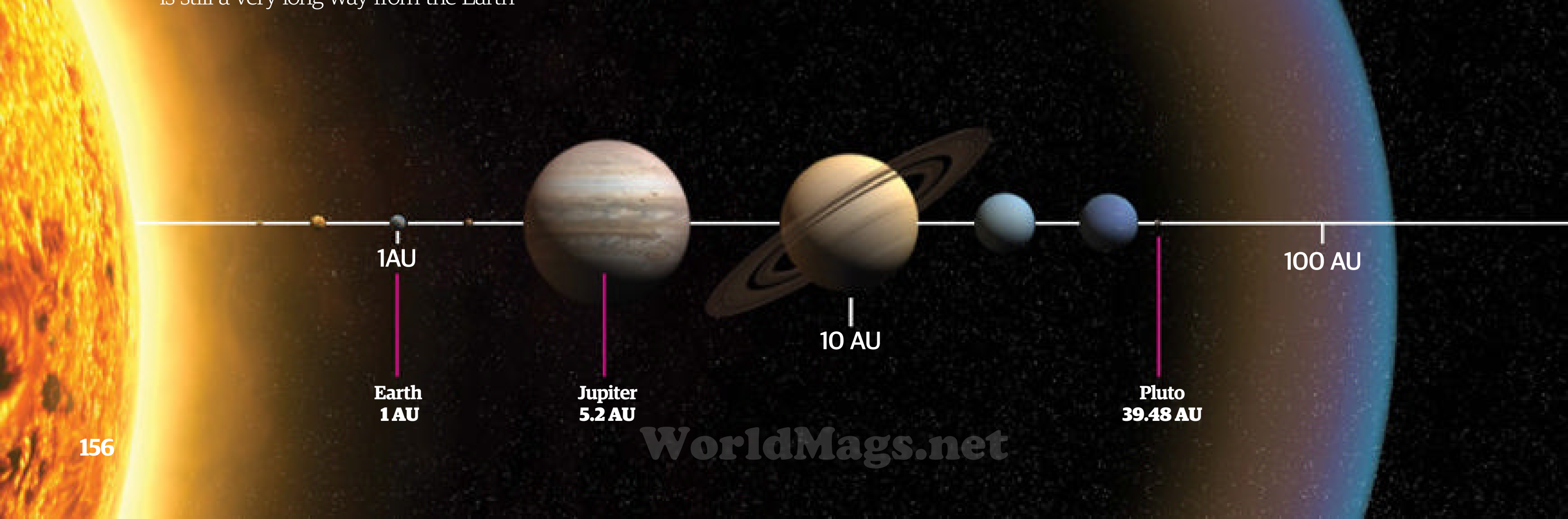
Although the closeness of Proxima Centauri has made for plenty of observation, there are* still some burning questions. Are there any planets orbiting the star? And if so, are they habitable? The Hubble Space Telescope hinted at the possibility of a planet near Proxima Centauri during observations in 1998, but no further evidence has appeared upon subsequent imaging. Proxima was to have been a target of the Space Interferometry Mission (SIM), a NASA space telescope mission that ultimately got cancelled. The star's closeness continues to make it a promising destination for both observation and actual interstellar travel, and eventually we'll get a better look at our neighbouring star.

Centaurus

The constellation Centaurus takes up about 1,060 square degrees and has 281 stars that are visible to the naked eye - more than any other constellation. Alpha Centauri is the constellation's most notable feature, but there's also Beta Centauri, the tenth-brightest star in the sky that's actually a binary star system. Alpha and Beta Centauri are used together as pointers to Crux (also known as the Southern Cross), a distinctive constellation used by navigators to determine direction. Aside from the stars, Centaurus is also known for its deep sky objects, such as planetary nebulas, star clusters and galaxies. Omega Centauri, a globular star cluster, is the largest and brightest one orbiting the Milky Way and contains several million stars. The galaxy Centaurus A is one of the closest active galaxies to Earth, and has a supermassive black hole at its centre.

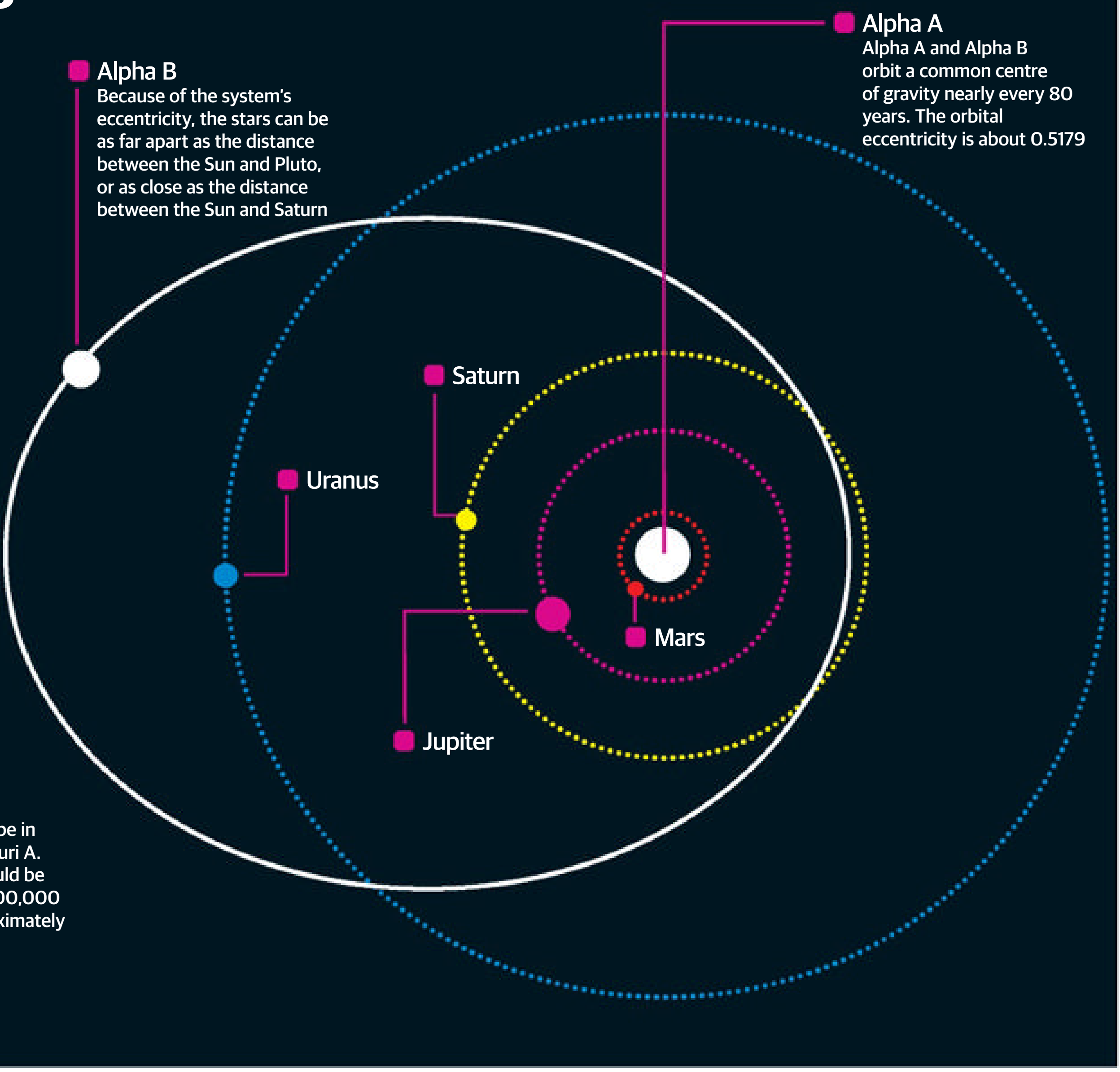
Distance to Proxima Centauri

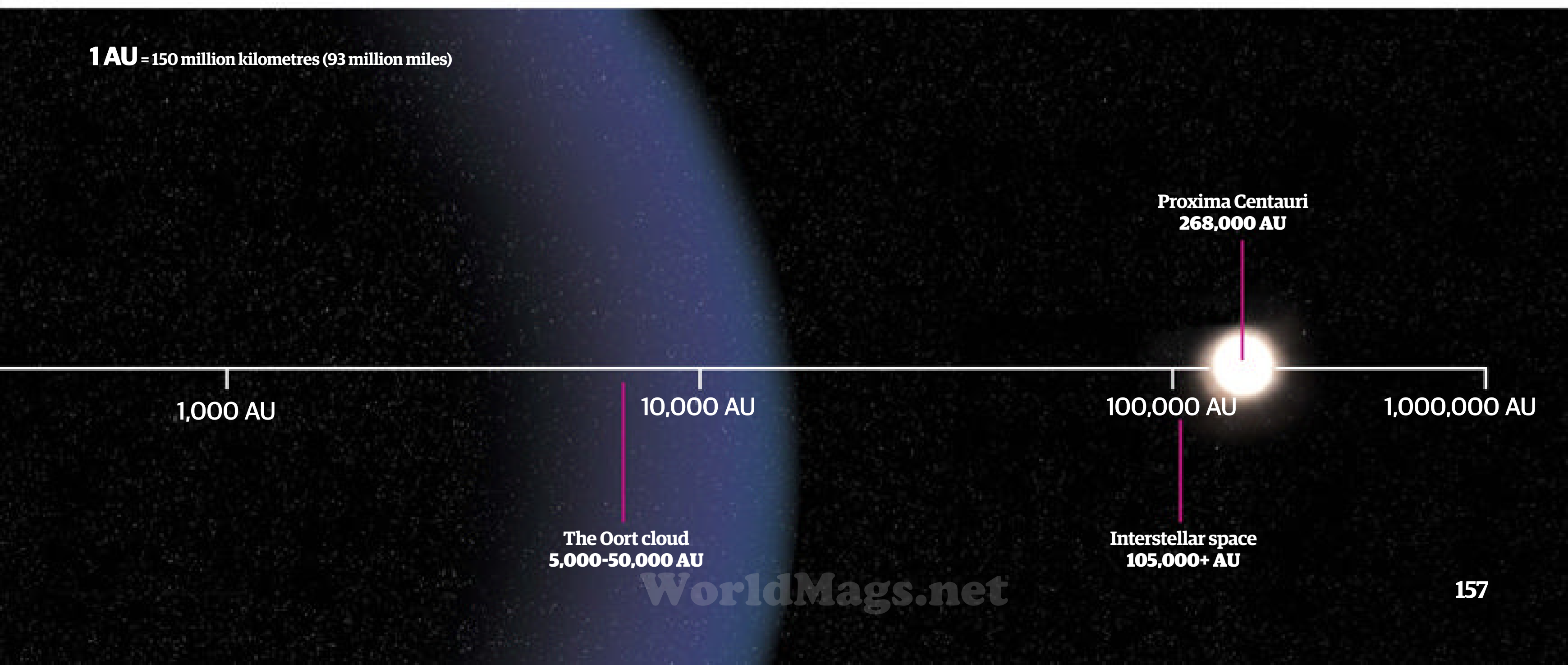
It may be the closest star after our Sun, but Proxima Centauri is still a very long way from the Earth



Comparing orbits

The orbits of Alpha Centauri A and B are larger than those of Mars, Jupiter, and Saturn, but smaller than that of Uranus. There could be a gravitational association between Proxima and the other two stars. If this is true, then Proxima is probably at its furthest point in its orbit right now. But it could also be on a hyperbolic trajectory - a special kind of orbit with an eccentricity greater than 1 - with respect to Alpha Centauri AB. This means that in theory, Proxima could eventually leave the system completely.





Proxima: inside and out

The closest star to our Solar System is also one of the dimmest and smallest red dwarfs

Proxima Centauri isn't just a red dwarf; it's on the lower end of range for late-type M-class stars with a mass of just 0.123 that of the Sun. They have dense, opaque interiors. Because of this, late-type red dwarfs have no radiative zone – an area outside the core where energy is transferred via radiation present in other types of stars. Instead, both the core and the outer layer, or envelope, are convective. Energy and hydrogen circulate freely. These types of red dwarfs continue to fuse hydrogen into helium in their cores until it's depleted. In contrast, the Sun will only use up about ten per cent of its hydrogen supply before it leaves the main sequence and goes into a red giant phase.

Compared to larger, more massive stars, the fusion process in red dwarfs is incredibly slow. As a result, the estimated life span of red dwarfs is longer than the age of the universe. The lower the mass of the star, the longer its lifetime, so Proxima's estimated life span is approximately 4 trillion years. As the hydrogen fuel is depleted, the core will contract and it will become a blue dwarf as its temperature rises to up to 8,200 degrees Celsius (14,800 degrees Fahrenheit) and its luminosity increases, giving it a blue appearance. Once the fuel is gone, Proxima Centauri will become a stellar remnant – first a white dwarf, and then a black dwarf as it no longer emits heat or light. Due to their lengthy life span, the life cycle of a red dwarf is theoretical.

Proxima Centauri is also one of the most active flare stars ever observed, generating X-ray emissions similar to those that come from the Sun. This means that on occasion it can suddenly have flashes of intense brightness. Proxima Centauri's flares are a release from its magnetic field, generated by the convection in the star's interior.

Some scientists have speculated that there is a habitable zone around Proxima Centauri, which would theoretically be a range of about 3.4 million to 8 million kilometres (2 million and 5 million miles) from the star, with an orbital period between 3.6 and 14 days. Red dwarfs emit very little light, and any planet in this zone would probably be tidally locked to the star – with one side remaining in perpetual darkness. This means that there may just be a small region on the planet that is actually habitable, or there would need to be a very thick atmosphere to keep the 'dark' side's temperatures up. In addition, a planet orbiting Proxima Centauri would need to have a strong magnetic field to counteract the effects of the star's flares on its atmosphere.

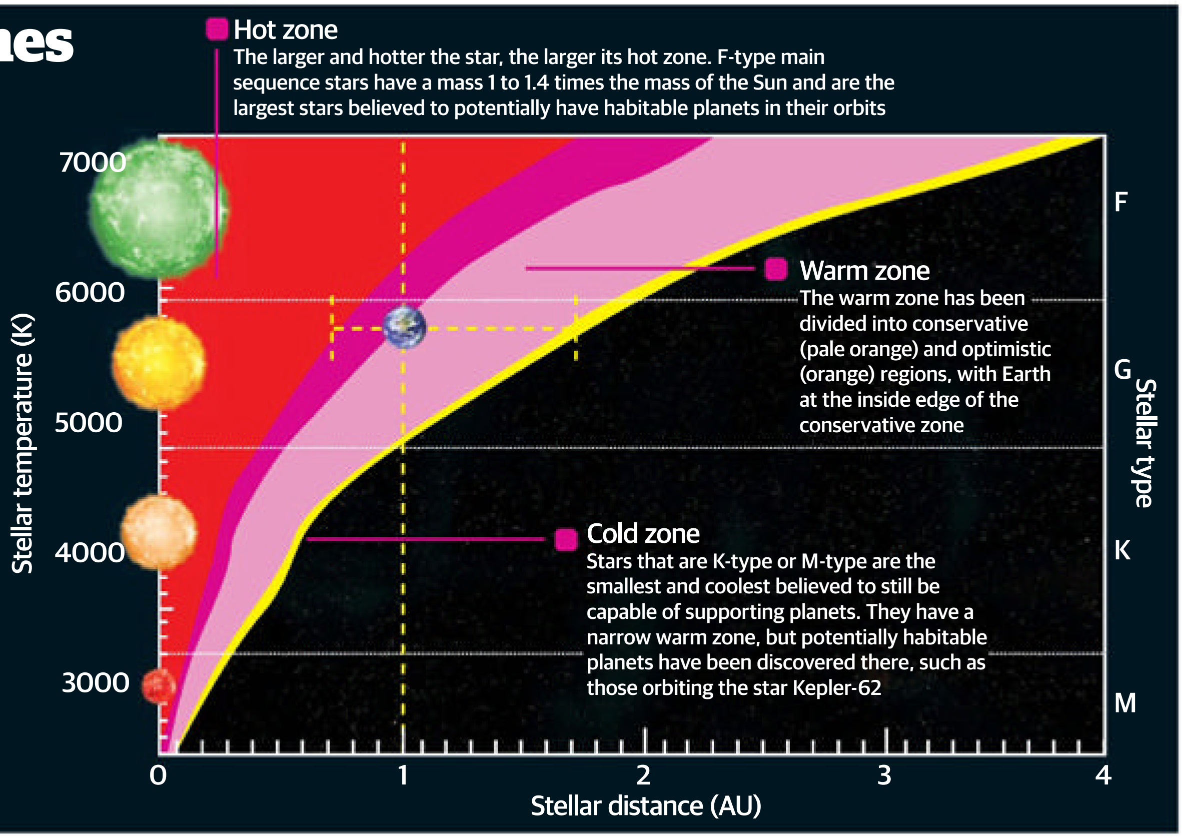
Other potential challenges include weather and winds, both of which may be harsh; and photosynthesis, which could be a very different process since red dwarfs emit most of their radiation in infrared light instead of visible light. One thing that red dwarfs have going for them is their long life; perhaps even if there isn't a habitable zone around Proxima Centauri now, there could be in the future. During the blue dwarf phase the star will be hotter and brighter, possibly allowing for previously uninhabitable planets to become habitable.

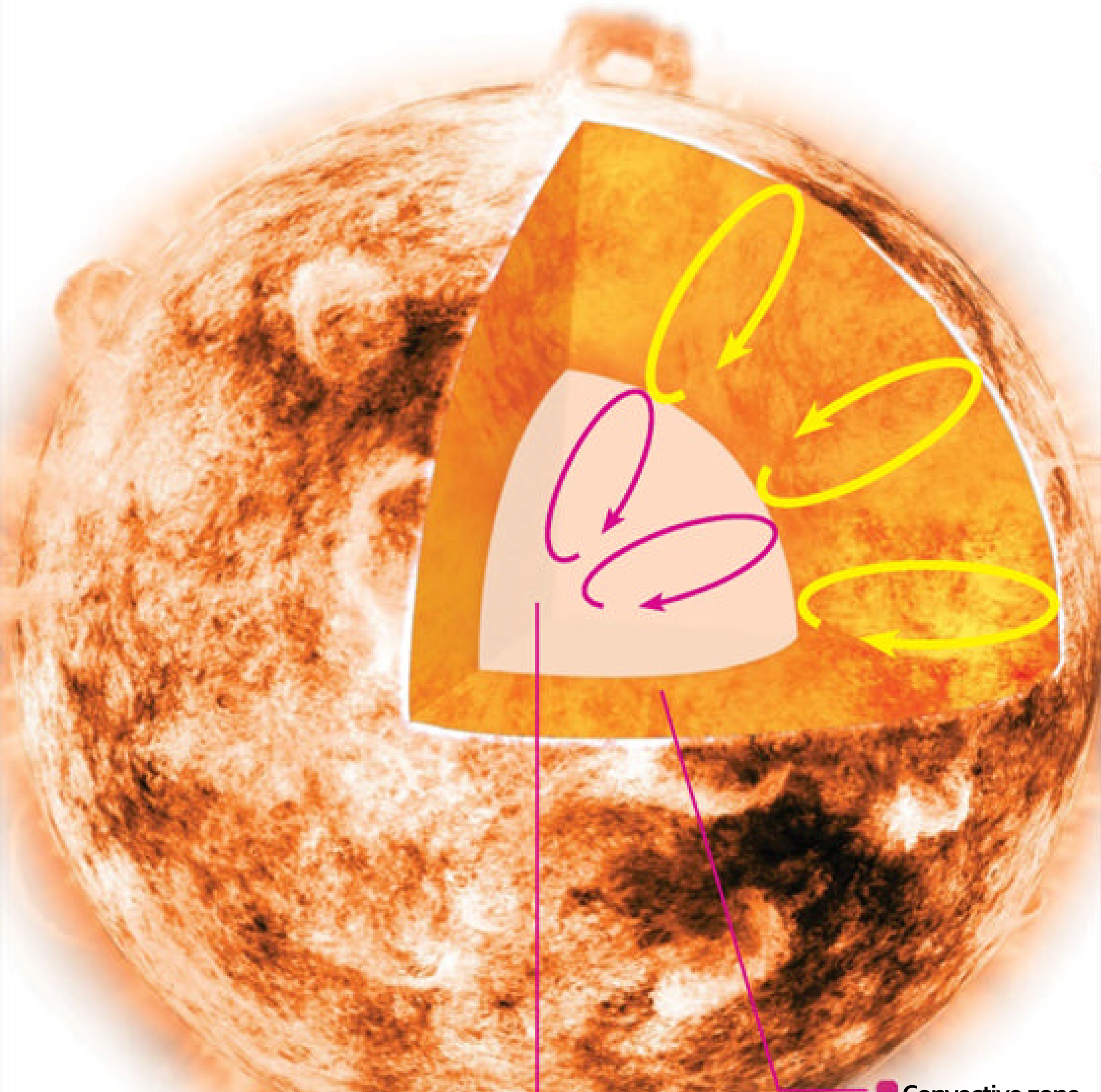
> "It's one of the most active flare stars ever observed"

Habitable zones

The habitable zone comprises areas around stars where life is theoretically possible on the orbiting planets. It is sometimes known as the circumstellar habitable zone, or the Goldilocks Zone because the circumstances are 'just right' – neither too hot nor too cold – for liquid water to be present on the planet's surface. In addition to temperature, there must also be adequate atmospheric pressure. While this seems simple enough, defining parameters for a habitable zone can be challenging. For our Solar System, estimates range from an inner edge of 108 million km (67 million miles) to an outer edge of 448 million km (278 million miles).

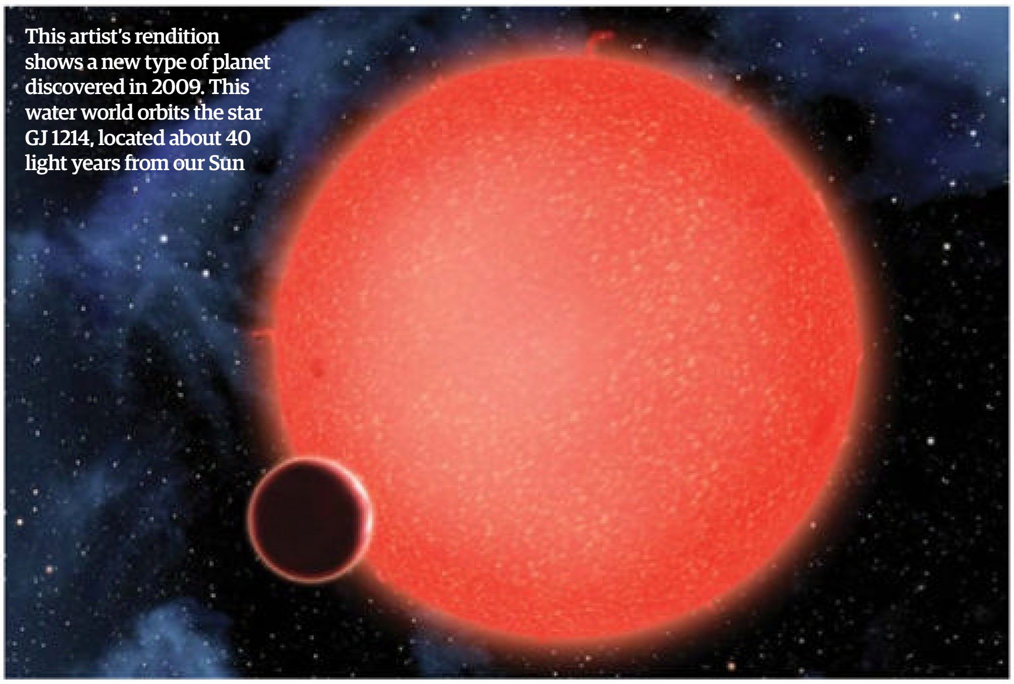
As for other solar systems, estimates for the number of habitable planets vary widely – from 500 million to over 150 billion. Some scientists point out that basing the criteria on our own biosphere amounts to carbon chauvinism – the assumption that all extraterrestrial life is carbon-based like life on Earth.





Core
Because red dwarf stars have a low mass, they are entirely convective (without the radiative zone of other stars). Hydrogen fusion takes place within the core and energy moves via circular currents to the outer envelope

Convective zone
The cooler outer layer of the star also contains hydrogen as well as helium (generated as a result of the fusion process). The hydrogen circulates back to the core, where fusion continues for the lengthy main sequence of the star



This artist's rendition shows a new type of planet discovered in 2009. This water world orbits the star GJ 1214, located about 40 light years from our Sun

Proxima Centauri in numbers

Quick facts and figures about our nearest stellar neighbour

6800

Proxima Centauri is around 6,800 times further from the Sun than Pluto

4 trillion years

Red dwarf stars like Proxima Centauri can last this long because they burn fuel at a slower rate

0.0017

Proxima's total luminosity over all wavelengths is 0.17% that of the Sun

27 million Kelvin

The flares on Proxima Centauri can reach this temperature – hot enough to radiate X-rays

40

Although it's smaller than the Sun in mass and diameter, Proxima is 40 times denser than the Sun

4.24

Light takes this many years to reach the Earth from Proxima

Exploring the stars

Could we travel to this distant neighbour and what problems would we encounter on the way?

Although Proxima Centauri is sometimes referred to as Alpha Centauri C, we aren't yet sure how it fits in with Alpha A and B. The stars in the binary system orbit around a common centre of gravity, and range from being 1.67 billion kilometres (1 billion miles) to 5.3 billion kilometres (3.3 billion miles) apart due to the eccentricity of their orbit. They're relatively similar and Sun-like.

By contrast, Proxima is smaller, redder, weaker and much further from the other two stars. Visually it appears as a faint red star near two very large bright stars – it doesn't seem to fit. However, Proxima has the same proper motion as Alpha Centauri AB; the angular changes in position over time are the same. Proxima could have been pulled into the system by the older stars, or formed at the same time.

Alpha Centauri and Proxima Centauri in particular, as the closest star to us after the Sun, is theoretically our first stop once we figure out the particulars of interstellar travel. Although it's close in terms of stars, the distance is the biggest challenge. We could get there, but it's going to take a long time. Using our current technology, it would take thousands of years. The Voyager 1 space probe has travelled further than any other, and is currently travelling in previously unknown space territory at around 60,000 kilometres per hour (38,000 miles per hour). If it were heading to Proxima, Voyager would take more than 70,000 years to reach the star.

In 2011, NASA's Ames Research Center and the Defense Advanced Research Projects Agency (DARPA) began collaborating on the 100-Year Starship Project. The purpose was to determine the requirements for meeting the goal of human interstellar travel within a century. Some currently feasible ways of reaching Proxima include ion propulsion engines and solar sails. The former creates thrust by accelerating ions, while solar sails harness radiation pressure of gases to push thin, sail-like mirrors to high speeds. Both concepts have been tested, but have not yet been used as a primary source of power.

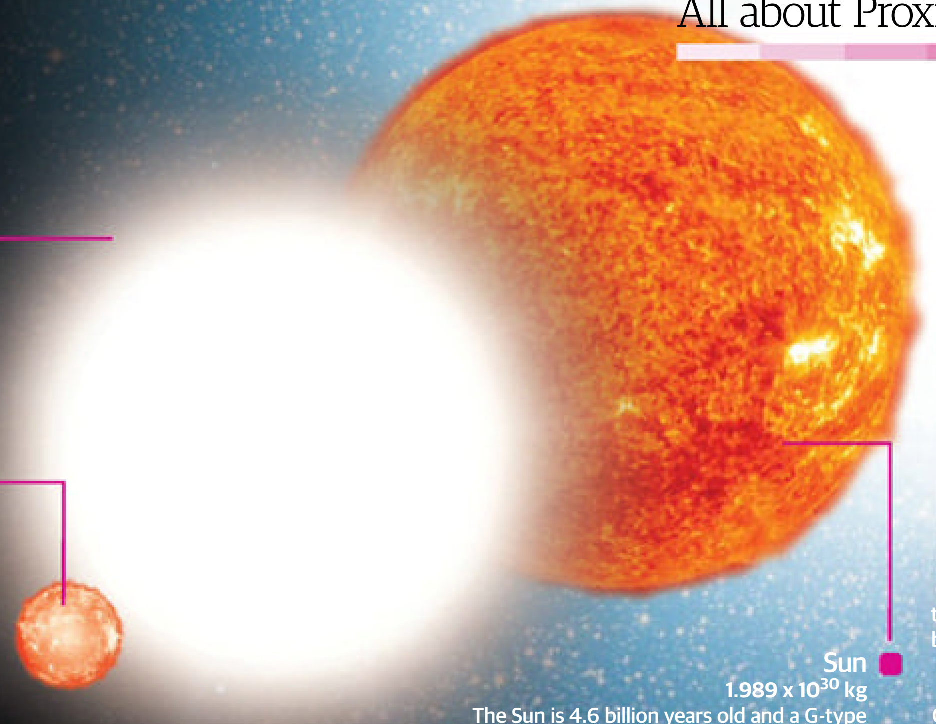
There is also a human cost to interstellar travel. If it's not possible to reduce the amount of time it takes to reach Proxima, we'd need multiple generations of astronauts; children would be born along the way and have to pick up where their parents left off. Even if we could get there in a century, that's longer than the average human lifetime. Space travel also causes bone and muscle loss, and the cardiovascular system loses some of its efficiency. There's also the matter of supplying and maintaining a spacecraft for a number of astronauts, for the trip there and back. Distance is just one challenge on our quest to reach the stars.

Seeing the star

Proxima Centauri might be a relatively small and dim star (being a red dwarf), but that doesn't mean it's only visible to the most sensitive telescopes – it can even be seen with a pair of binoculars from Earth. However, because it's so close to Earth it has become a subject of exoplanet hunters in recent years and for that you need some serious hardware, well beyond the most fervent of amateur stargazers. Since the hunt for exoplanets escalated among the space agencies in the Nineties, Hubble, ALMA and Kepler have trained their instruments on this nearby star.

NASA's Hubble Space Telescope (inset) and the European Southern Observatory's ALMA (Atacama Large Millimeter/submillimeter Array) in Chile, are among the most famous of the observatories that have scrutinised Proxima Centauri

Mass matters



Alpha B
0.907 Solar mass
As the secondary star in the system, Alpha B is slightly smaller. It is more orange and a K-type main sequence star – cooler than Alpha A and the Sun

Proxima
0.123 Solar mass
Proxima Centauri is tiny in comparison to the other stars in the Alpha Centauri system. It is about 4.85 billion years old; potentially older than our Sun but a great deal smaller. It's an M-type star, either main-sequence or sub-dwarf

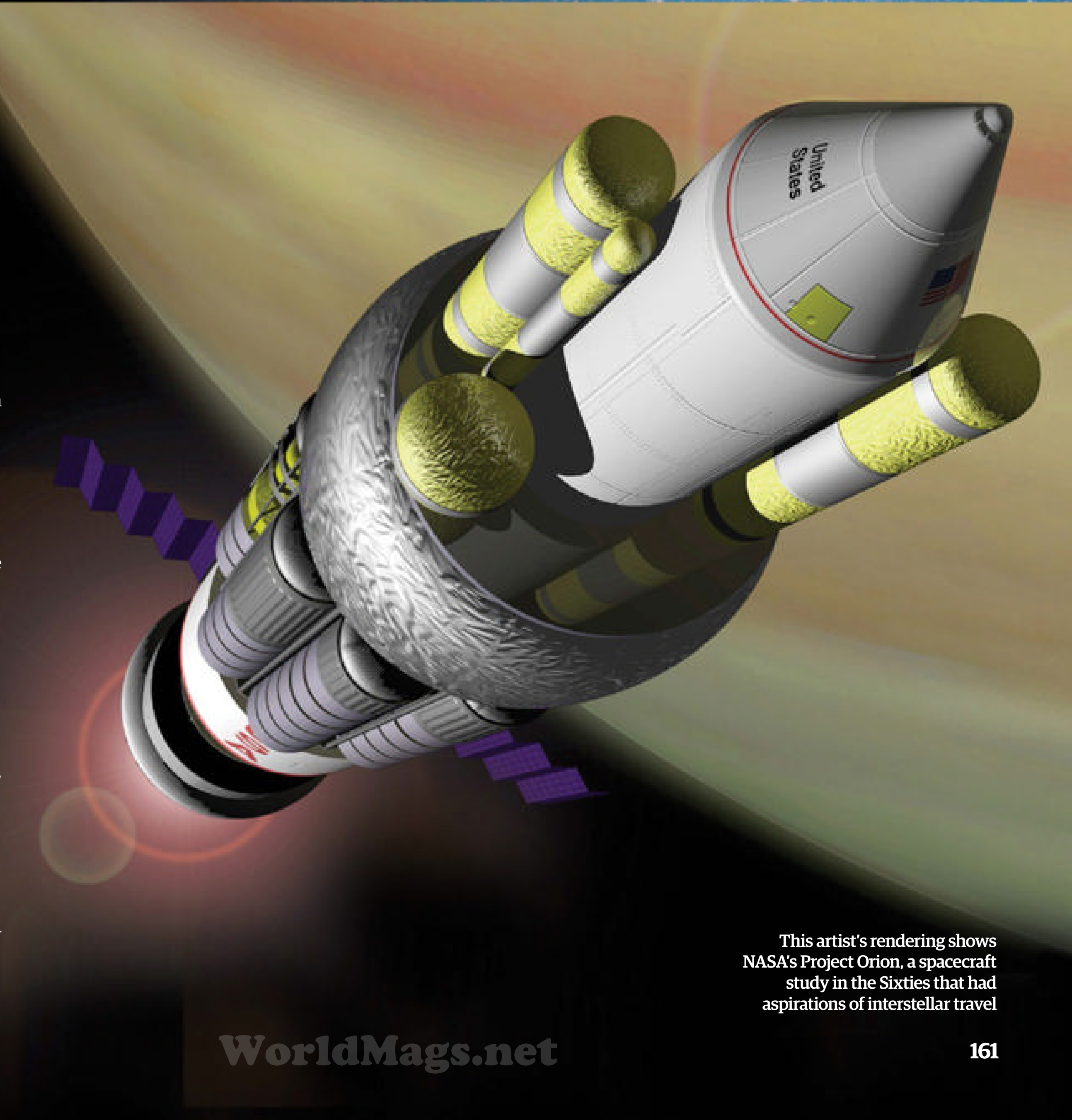
Sun
1.989×10^{30} kg
The Sun is 4.6 billion years old and a G-type main sequence star, sometimes called a yellow dwarf. It's very similar to Alpha Centauri A

Alpha A
1.100 solar mass
Both Alpha Centauri A and B are estimated to be between 5 and 6 billion years old. Alpha A is just a bit bigger than our Sun, and a G-type main sequence star with a similar yellow colour

Interstellar travel

We've long been studying ways to achieve interstellar travel. In the late-Fifties, NASA had Project Orion. This spacecraft would have used nuclear pulse propulsion - a series of exploding atomic bombs - to propel it the distance needed to reach Mars, Saturn and ultimately another star. The British Interplanetary Society studied the possibility of a spacecraft to the stars in the Seventies, called Project Daedalus. Daedalus had the goal of taking no longer than a human lifetime to reach its destination, requiring a speed greater than the capabilities proposed for Project Orion. It would have needed a very powerful fusion rocket. Then, in the late-Eighties, NASA tried again with Project Longshot, an unmanned probe designed to be built and launched at Space Station Freedom, the predecessor to the International Space Station. Instead of a closed fusion rocket for power, Longshot would have used a nuclear fission reactor.

So what happened to keep these projects concept only? For Orion, the Partial Test Ban Treaty, signed in 1963, rendered it impossible. The treaty banned the test detonation of nuclear weapons, except underground. Both Project Daedalus and Project Longshot require significant advances in nuclear fission technology to be viable. Today we don't have the ability to get to Proxima Centauri in less than a thousand years, much less a hundred years.



This artist's rendering shows NASA's Project Orion, a spacecraft study in the Sixties that had aspirations of interstellar travel

When galaxies collide

These two interacting galaxies are providing us with a rare opportunity to observe a galactic collision

This stunning image, taken by the Hubble Space Telescope, shows the individual galaxies UGC 1810 (top) and UGC 1813 (bottom) in the process of colliding. Together, this pair of interacting galaxies is known as Arp 273. The interaction of galaxies is thought to be relatively common in the universe, particularly within galactic clusters, however, the opportunity to directly observe one such as this is incredibly rare.

The two galaxies are located around 300 million light years from Earth in the Andromeda constellation. A collision is actually thought to have already occurred, with UGC 1813 passing through the five times more massive UGC 1810. As a result, the smaller galaxy is now showing signs of intense star formation at its nucleus. It is possible, though, that they will collide again in the future due to their gravitational attraction.

Most galactic collisions result in the merging of the two galaxies' cores, but it's unknown if that will happen in this example. What can be seen is a 'bridge' of sorts between the two where their spirals have been pulled apart by the other. It is thought that the interaction of Arp 273 may bear similarities to the eventual fate of our own galaxy when we collide with Andromeda in around four and a half billion years.

The Sombrero Galaxy

The space phenomenon that's two types of galaxy at once

Located approximately 28 million light years from Earth, this odd-shaped galaxy has been the focus of much attention from scientists around the world. The Sombrero Galaxy, or Messier 104, gets its name from its somewhat hat-like appearance. The bright galaxy is found towards the southern edge of the Virgo cluster of galaxies.

The Sombrero Galaxy contains about 2,000 globular clusters, collections of up to a million old stars held together by gravity that are often found in the halo of galaxies. By comparison, our Milky Way only has about 200. The Sombrero also contains several hundred billion stars and is approximately 50,000 light years across, around half the diameter of the Milky Way.

Around the brim of the galaxy are thick dust lanes that block the light at the centre, while the central bulge is made of old stars. Although the disc might be thin, the bulge, containing a black hole billions of times more massive than the Sun, can be seen extending both above and below the galaxy in this image from NASA's Hubble Space Telescope.

One of the most interesting things about the Sombrero Galaxy is that it seems to have a split personality. Most galaxies we know of are either spherical clusters of stars or slender discs, but the Sombrero appears to be both. Observations by NASA's Spitzer Space Telescope suggest that it is a round elliptical galaxy with a flat disc inside. The cause of this unique structure is unknown, although it's possible the Sombrero Galaxy was inundated with gas over 9 billion years ago, forming this additional mini-galaxy within.

This infrared image of the Red Square Nebula highlights its amazingly bizarre symmetrical appearance

Red Square Nebula

The unknown origins of this nebula make it one of the most mysterious objects we know of

This image, created by combining infrared exposures from the Mount Palomar Hale telescope in California and the Keck-2 Telescope in Hawaii, is puzzling to say the least. Its symmetrical and ordered square shape looks like something that was put together in Photoshop, but it's very much real and equally as interesting.

The Red Square Nebula, or MWC 922, is found in the night sky near the Serpens constellation. It is a bipolar nebula, which refers to its symmetrical appearance around a central point, and it is one of the best examples of such a nebula that we know of in the universe.

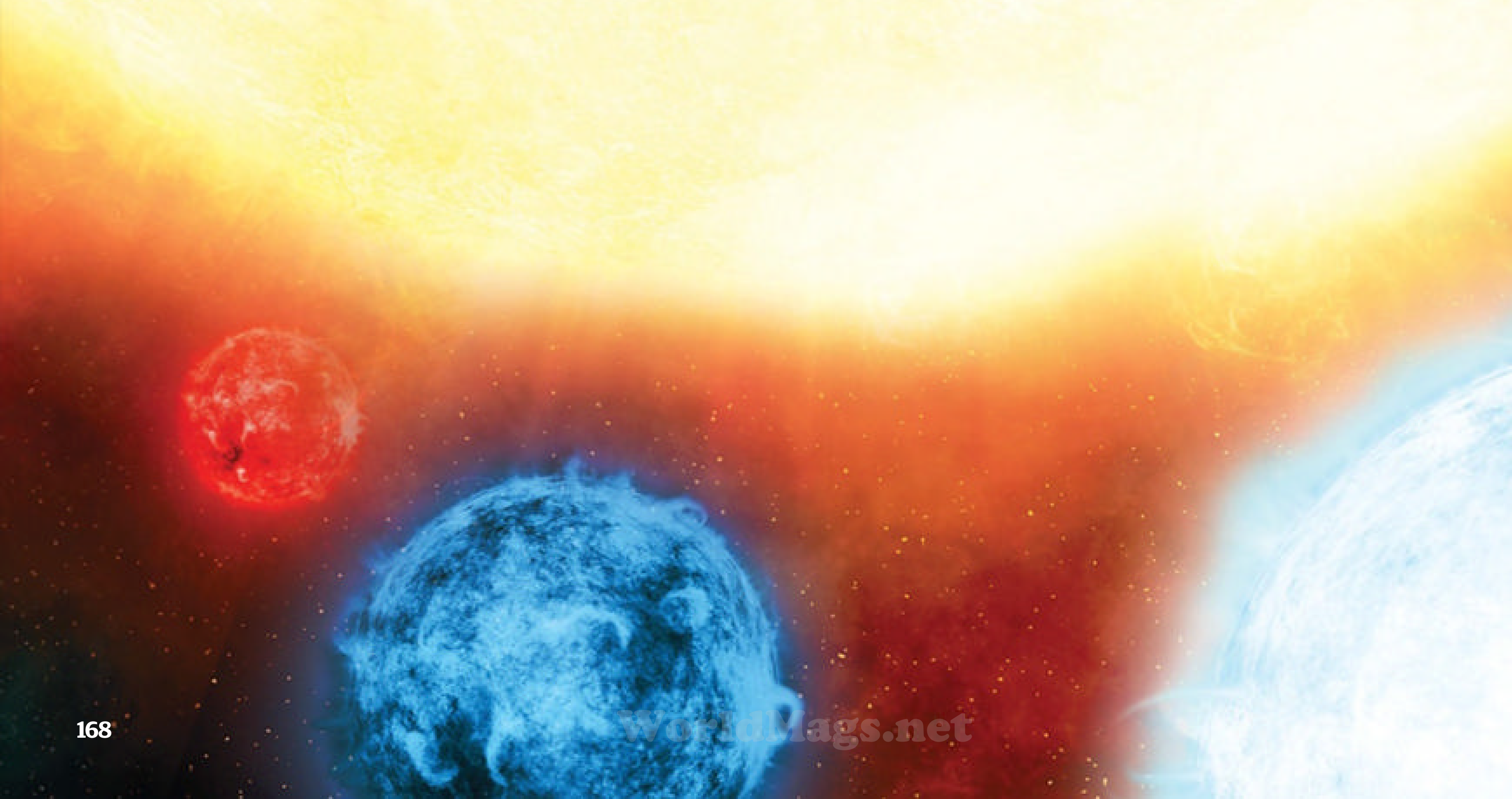
Its central star is responsible for the appearance of the nebula. It is thought that this star expelled cones of gas during later development stages of its life in opposite directions, visible in this image moving diagonally up to the right and downwards to the left. Amazingly, the edges of the cones form almost a perfect right angle with each other, creating a bright central square and a slightly dimmer outer square.

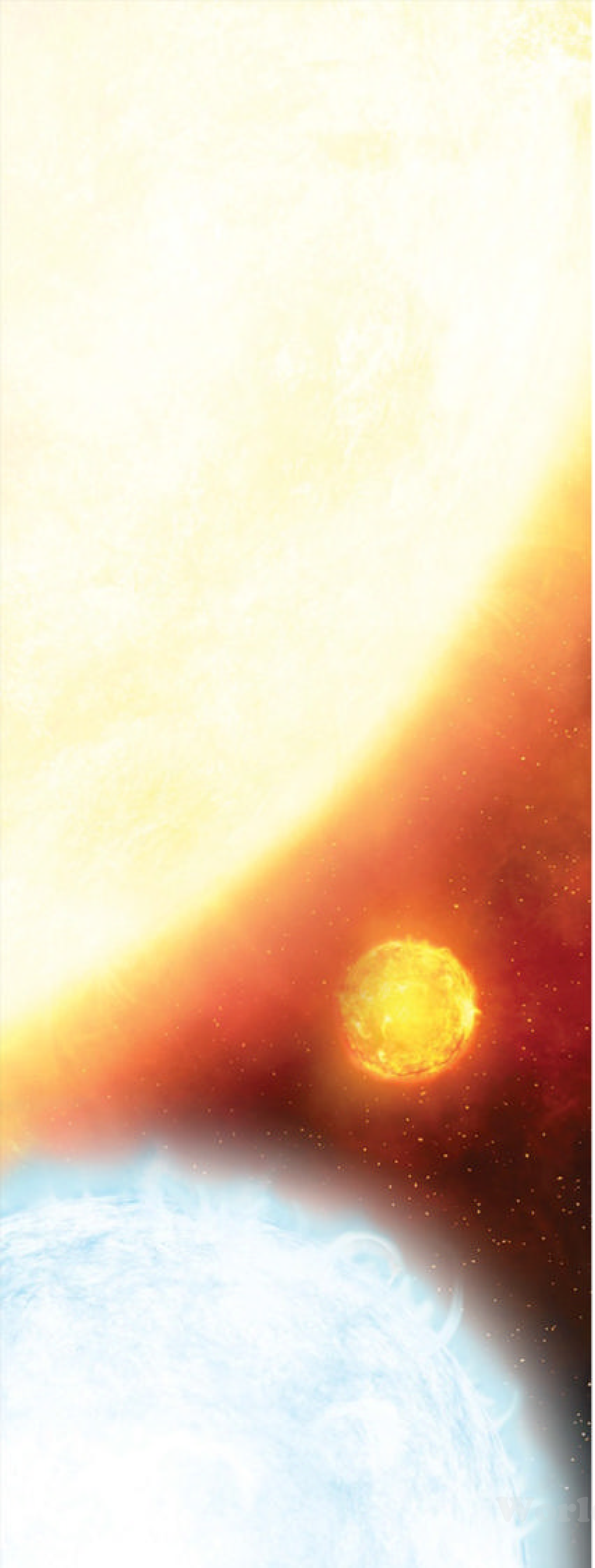
Stars are known to throw off material in this manner during the latter stages of their life, either prior to a supernova explosion or as the star runs out of fuel and loses its outer layers. Along the walls of the cone can be seen radial spokes emanating from the star, which further supports this hypothesis.

An observer looking side on to the nebula rather than straight on, like us here on Earth, would likely observe a different nebula altogether. They would instead see rings of material being ejected from the central star, an indicator that this is indeed a star on its way to going supernova. When this might be, or whether it will actually happen, is anyone's guess. For now, though, we can merely revel in the glory of this fantastic nebula and hopefully find others like it that might help unearth the mystery of its past, present and future.

Hypergiant stars

They're the biggest stars in the universe – cosmic monsters up to a million times brighter than the Sun – so how do supergiant and hypergiant stars push the limits of astrophysics?





Hypergiant stars

Look up at the sky on a dark night, and you'll see hundreds of stars. But only a few will really stand out – have you ever wondered why? For some, it's simply because they're quite close to Earth. For instance, Sirius is just 8.6 light years away – so, even though it's a fairly average star (though still 25 times more luminous than our Sun) it appears as the brightest star in our sky.

But other stars appear bright because they really are. The second brightest star in the sky, Canopus, is one such star – 310 light years from Earth and some 15,000 times more luminous than the Sun.

Stars in this class are usually known as supergiants – they have the mass of ten or more Suns, and evolve in a very different way from lower-mass 'Sun-like' stars, living fast, squandering their nuclear fuel and dying young in spectacular supernova explosions. The most massive stars of all, containing many tens or even hundreds of solar masses of material, are hypergiants, the most extreme stars known.

"In astronomy I think there's a natural tendency to be attracted to extremes," explains Professor Paul Crowther from Sheffield University. "Whether that's the most extreme by physical size, which are generally the cool red supergiants, or the most extreme by mass, which are the hottest and brightest blue hypergiants."

And Crowther should know – he's devoted much of his career to studying these stellar monsters, and in 2010 discovered the most extreme hypergiant so far, a stellar beacon 165,000 light years from Earth in the independent Large Magellanic Cloud galaxy, an incredible 9 million times more luminous and 265 times more massive than the Sun.

Supergiants and hypergiants were first discovered through the theoretical tools of astronomy – in particular the Hertzsprung-Russell (H-R) diagram which allows astronomers to visualise the properties of stars en masse. However, the word 'giant' can be somewhat confusing, because in this case it combines concepts of mass and size. The largest stars by diameter can all be loosely defined as 'red giants' – an evolutionary phase that most stars pass through near the end of their lives, during which they swell to huge diameters (often larger than Earth's orbit around the Sun) and become far more luminous as they pump out more energy, but conversely turn red thanks to the coolness of their vast outer surfaces. The more massive a star is, the bigger it will grow as a red giant, and red supergiants with tens of solar masses (such as VY Canis Majoris, with a diameter larger than Jupiter's orbit around the Sun) are indeed the largest stars of all. However, really monstrous heavyweight stars never actually reach this stage, so while the larger a red giant is, the more massive it will be, the most massive stars of all aren't actually the largest.

The most massive stars are born at the heart of collapsing star-forming nebulas, where gas and dust are most readily available. Unlike the more sedate, Sun-like stars, which form around the edges and coalesce over many millions of years, these stellar heavyweights grow to their enormous proportions in just a hundred thousand years. The overall amount of raw material in the nebula (reflected in the size of the star cluster that emerges from it) also has a role to play.

"There seems to be a broad relationship between the total mass of a cluster, and the most massive star within it – so for instance the Orion Nebula has a mass of 1,000 Suns, and its most massive stars are about 30 times that of the Sun, while the NGC 3603 cluster has about 10,000 solar masses of material, and its most massive stars weigh around 100 solar masses. We don't know quite why this 'mass function' is the way it is in young star clusters, but it seems to be a universal rule," says Crowther

Competition between the massive central stars seems to act as a throttle to the formation process, ensuring that really massive stars are increasingly rare. "The next obvious question is whether if you had an even more massive cluster, would the mass of its biggest star keep going higher?" says Crowther. "And the answer seems to be no – we suspect there's a limit and it's linked to the star formation process. A star forms in a collapsing nebula full of competing stellar 'seeds', and it has a limited time to grab as much material as it can, or else its neighbours will. It's a bit like throwing a handful of sweets into a crowd of children – the ones nearest the centre will grab most of them really quickly, while those at the edges hardly get any. It's a competitive environment, and that probably puts an upper limit on how massive a star can get."

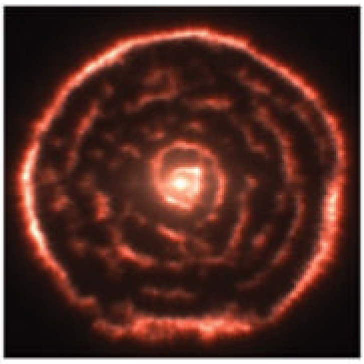
Another major difference between normal and monster stars lies in the nuclear reactions that keep them shining. In low-mass stars, these reactions are dominated by the 'proton-proton (p-p) chain', a process in which individual hydrogen nuclei

fuse together one reaction at a time, to eventually produce nuclei of helium, the next heaviest element. The p-p chain releases small amounts of energy at every step, but proceeds relatively slowly allowing Sun-like stars to keep shining for billions of years.

In more massive stars, however, another process called the CNO cycle becomes important. This fusion chain also converts hydrogen nuclei into helium, but it uses carbon nuclei as a sort of 'catalyst', allowing the reactions to happen at a much faster rate. The CNO cycle becomes increasingly dominant at higher temperatures and densities, and causes heavyweight stars to shine many thousands of times more brightly than their less massive neighbours. But the price for this brilliance is a drastically shortened life span - even though their cores contain much more nuclear fuel than those of Sun-like stars, massive stars exhaust themselves in just a few million years and begin to swell into supergiants or hypergiants.

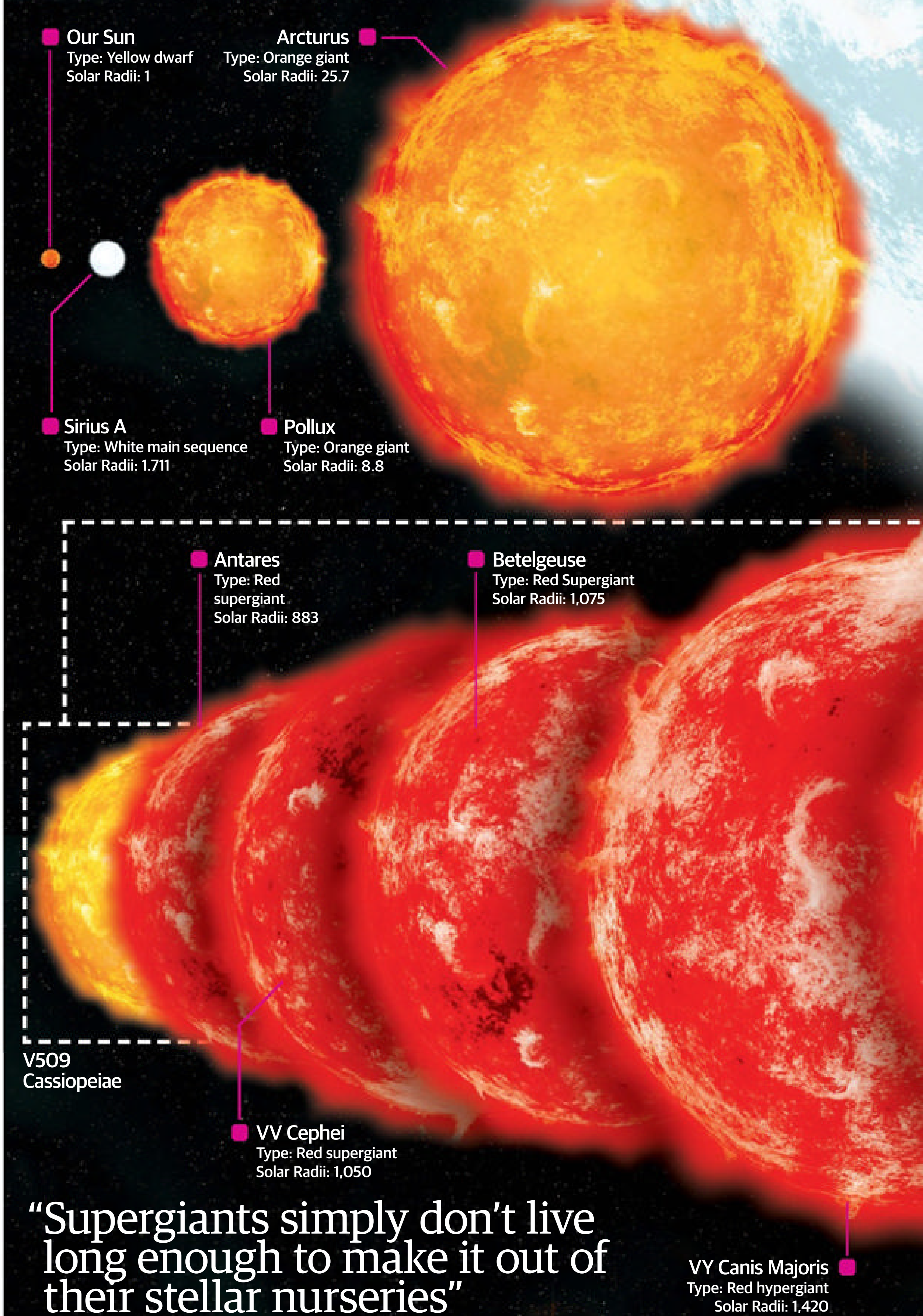
This short life span means that supergiants are almost always found at the heart of newborn star clusters - these clusters disintegrate over millions of years, eventually scattering their longer-lived stars over a broad region of space, but supergiants simply don't live long enough to make it out of their stellar nurseries.

"These stars are incredibly rare - they only form in a few places and have very short lifetimes, so even if you find a star cluster that's just 5 million years old, its most massive stars will already have died," says Crowther. "There's only a handful of really young, massive clusters close enough to Earth for us to look for these guys and they're losing mass at a terrific rate, so the mass we measure depends on just how old the stars happen to be. The places where you usually find these really massive clusters tend to have enhanced star

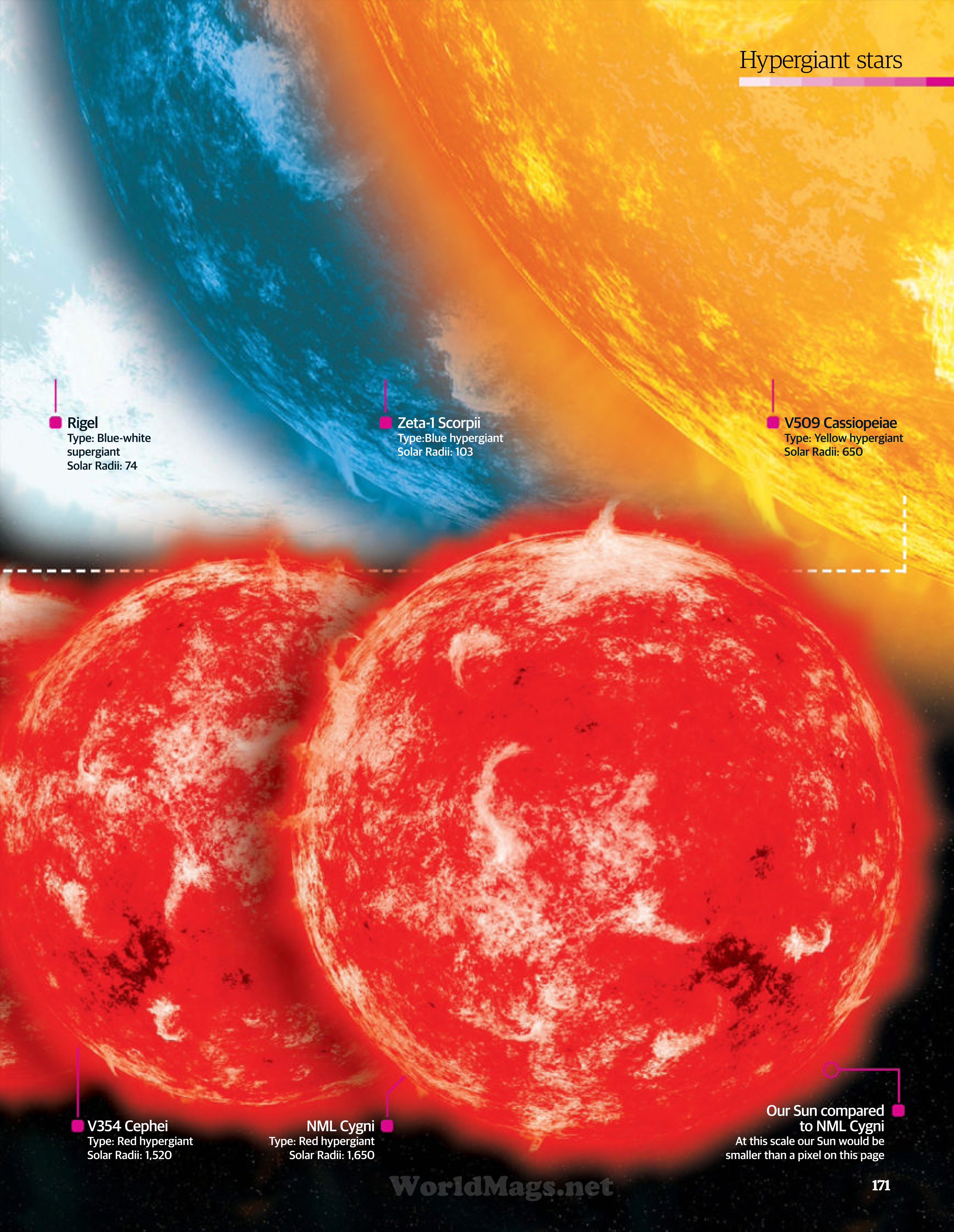


This image shows a spiral structure in the material around the R Sculptoris star

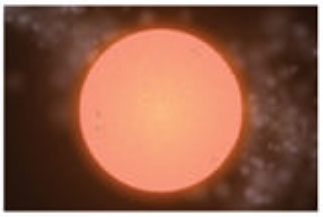
The size of stars



"Supergiants simply don't live long enough to make it out of their stellar nurseries"

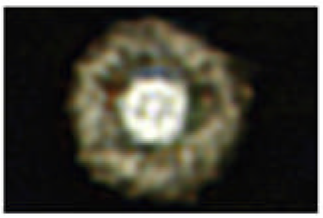

Rigel
Type: Blue-white supergiant
Solar Radii: 74
Zeta-1 Scorpii
Type:Blue hypergiant
Solar Radii: 103
V509 Cassiopeiae
Type: Yellow hypergiant
Solar Radii: 650
V354 Cephei
Type: Red hypergiant
Solar Radii: 1,520
NML Cygni
Type: Red hypergiant
Solar Radii: 1,650
Our Sun compared to NML Cygni
At this scale our Sun would be smaller than a pixel on this page

Types of giant stars



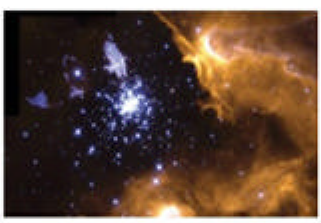
Red supergiant

The biggest red giants are the largest stars in the universe, swollen to diameters of a billion kilometres or more by changes in their cores as they near the end of their lives. As they swell in size and brighten to hundreds of thousands of times solar luminosity, their surfaces cool to a distinctive red colour. But many scientists say these stars are supergiants rather than true hypergiants.



Yellow supergiant

Yellow supergiants seem to be a rare intermediate stage, though again they get their name from their size and brightness rather than their mass. They seem to be red supergiants that have shed large amounts of their outer gas as they head towards a supernova explosion. In this photo of the 'Fried Egg Nebula', rings of ejected material can be seen surrounding the central star.



Blue hypergiant

Blue hypergiants are the real heavyweights of the universe – tens or even hundreds of times more massive than the Sun, and millions of times more luminous. Their powerful gravity limits their size, so their surfaces are intensely hot. The young star cluster NGC 3603, shown here, contains one binary system whose stars contain a staggering 90 and 120 solar masses of material.

formation rates, usually due to galactic collisions or interactions."

So what do supergiants and hypergiants look like? The truth is that they're surprisingly varied – while the H-R diagram might suggest that they'd all have extremely hot surfaces and appear blue in colour, in reality they range across the spectrum of colours. Supergiants show the most variety, and it seems that their colours simply reflect the precise balance between the inward pull of gravity and the outward pressure generated by its radiation at a particular phase in their lives. This balancing act, known as 'hydrostatic equilibrium' governs a star's overall diameter and therefore its surface area: even highly luminous stars can display Sun-like yellow, or even cooler red surfaces if they are large enough for the heating effect of their escaping radiation to be thinly spread.

Most stars retain more or less the same mass throughout their lives, and therefore maintain the same gravity, so their equilibrium is mostly affected by changes to their luminosity as the nuclear reactions in their cores change and evolve – from this, we can work out that blue supergiants are still close to the 'main sequence' of stellar evolution, while yellow ones have begun to swell in size as they reach

"The borderland between supergiants and hypergiants is filled with unusual stars"

the end of their lives. Red supergiants are even further along their life cycle, and are the largest stars of all.

But for really massive hypergiant stars, there's a different story. These stars never make it across to the red side of the H-R diagram – instead their brilliant radiation generates such huge pressure that it blows their outer layers away into space, exposing the interior and ensuring that such stars remain hot, maintaining blue or white-hot surfaces throughout their lives. This strong outflow of hydrogen-rich material gives itself away in a hypergiant's spectrum and is one of the key means of distinguishing them from really bright supergiants.

The borderland between supergiants and hypergiants is filled with a strange variety of unusual stars, and no two astronomers really agree on the precise dividing lines between them. For example, luminous blue variables are extremely bright stars that show long, slow changes in brightness with occasional outbursts, and include both supergiant and hypergiant stars.

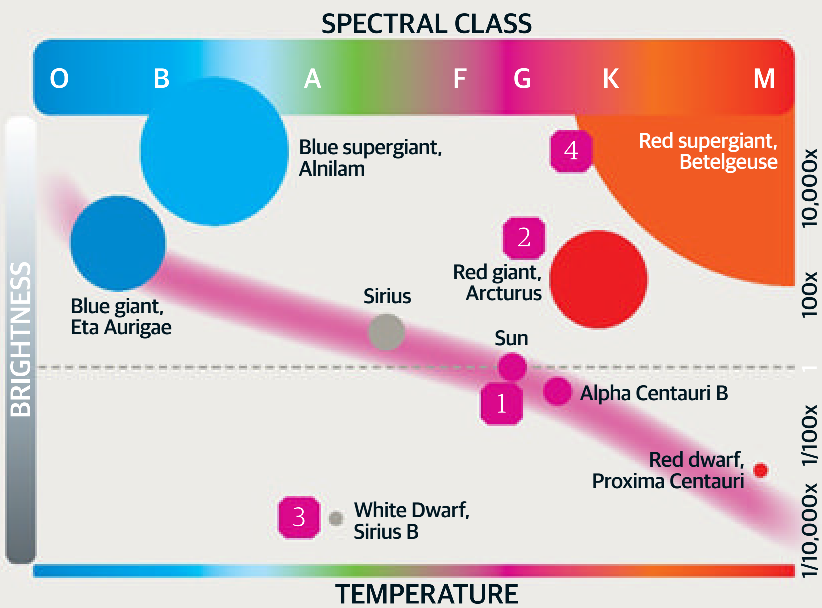
Most of the rare so-called 'yellow hypergiants', despite their name, actually seem to be red supergiants that are shedding their outer layers and heating up. And, as we've seen, astronomers also differ about whether red hypergiants even exist! Depending on their features displayed in their light, other categories of supergiant or hypergiant bear exotic names such as Wolf-Rayet stars and Ofpe stars.

However, until recently, the only certain means of weighing really massive stars, and identifying supergiants and hypergiants, was to pick them out in binary systems. Here, the orbital motions of the two stars can be used to calculate their masses. Fortunately, a recent breakthrough in modelling the behaviour of really high-mass stars promises to remove some of these limitations.

Supergiant and hypergiant stars live fast and die young, but what fate awaits them at the end of their lives? Once a star has exhausted the hydrogen fuel in its core, it has reached the end of its main sequence lifetime

Star classification

One of the most useful tools for classifying stars is the Hertzsprung-Russell (H-R) diagram. It plots stars according to their surface temperature and colour or 'spectral type' (on the horizontal axis) and their luminosity (on the vertical axis). When a large number of randomly selected stars are plotted, a pattern soon emerges: most stars are arranged along a diagonal ribbon known as the 'main sequence', that runs between the faint, cool and red and the bright, hot and blue. Luminous cool stars and faint hot ones ('red giants' and 'white dwarfs') occupy regions to either side of the main sequence and are comparatively rare.



1. Main sequence

This is the region where stars spend the majority of their lives – a star's position on the main sequence is largely determined by its mass.

2. Red giants

Most stars pass through this phase near the end of their lives, brightening and developing an atmosphere with a cool surface.

3. White dwarfs

These hot stars are faint because of their tiny size – they are the burnt-out, slowly cooling cores of stars like our own Sun.

4. Supergiants

These high-mass stars are brilliantly luminous and display a variety of colours as they move back and forth across the H-R diagram.

Structure of a supergiant

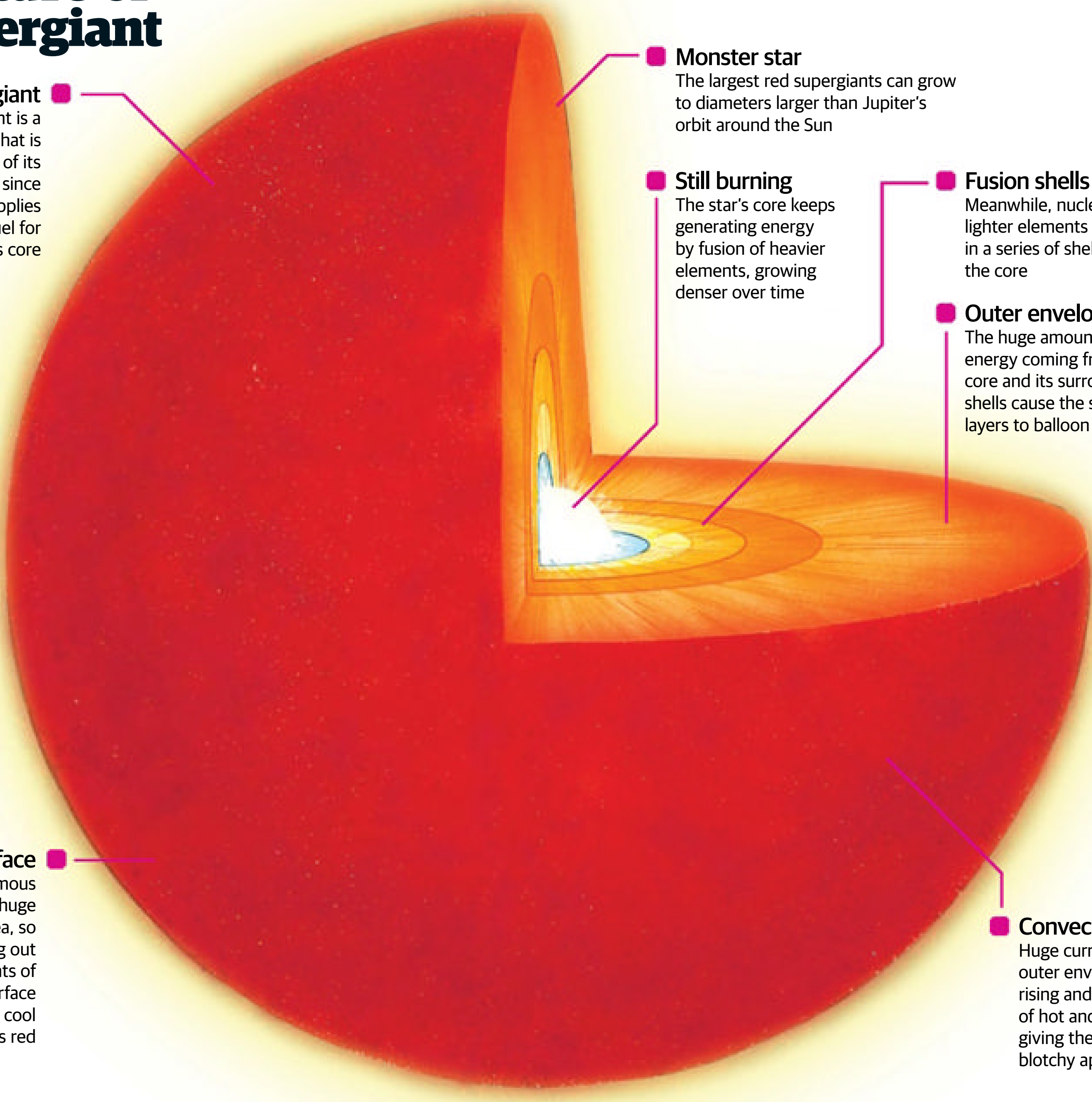
Red supergiant
A red supergiant is a high-mass star that is nearing the end of its life and has long since exhausted the supplies of hydrogen fuel for fusion in its core

Monster star
The largest red supergiants can grow to diameters larger than Jupiter's orbit around the Sun

Still burning
The star's core keeps generating energy by fusion of heavier elements, growing denser over time

Fusion shells
Meanwhile, nuclear fusion of lighter elements spreads out in a series of shells around the core

Outer envelope
The huge amounts of energy coming from the core and its surrounding shells cause the star's upper layers to balloon in size



Cool surface
The star's enormous size gives it a huge surface area, so despite pumping out huge amounts of energy, the surface remains relatively cool and appears red

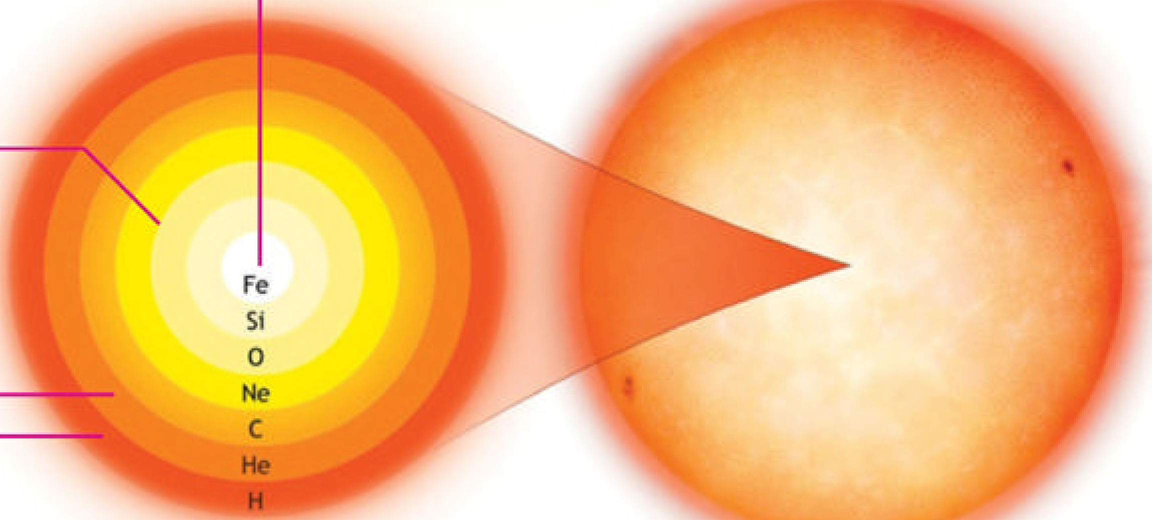
Convection cells
Huge currents within the outer envelope create rising and sinking masses of hot and cool gas, often giving the star's surface a blotchy appearance

Iron core
Just before the star dies, a core of solid iron begins to build up. Unlike the lighter elements, iron fusion absorbs, rather than releases energy, triggering the core's collapse and a supernova explosion

Heavier shells
Closer to the core, heavy elements continue to fuse into still heavier ones, allowing the supergiant to keep shining

Helium fusion
A second shell of helium fusion follows the hydrogen shell out into the star, creating heavy elements such as carbon and oxygen

Hydrogen fusion shell
Changes in the star's density and temperature allow hydrogen fusion to continue in an expanding shell around the core after hydrogen in the very centre has been exhausted



and can only continue to shine by burning hydrogen from the shell surrounding the core, and heavier elements in the core itself. These processes cause the dying star to brighten and swell, shifting it towards 'red supergiant' territory, while its core develops a complex layered structure of increasingly heavy elements. Each new phase of fusion produces less energy than the previous one, and is exhausted more quickly, but the radiation that continues to pour from the core still helps to support it against its own enormous gravity.

That all changes when the star attempts to fuse iron - the first element whose fusion absorbs energy. Abruptly, the star's power supply falters and dies, and the huge weight of its outer layers comes crashing down. In what is known as a 'core-collapse supernova', the iron-rich core is compressed to a tiny size, while a tremendous shockwave rebounds through the remainder of the star, heating and compressing it until the whole star ignites in a blaze of nuclear fusion that may last for months and outshine a billion stars. As the supernova fades and the debris clears, the compressed remains of the core may be revealed as a super-dense neutron star, or even a black hole.

But, for the most massive stars of all, there may be a third option. "Theorists tell us that if a star dies with roughly 200 solar masses of material remaining, it could just blow up - it wouldn't be the usual core-collapse event, but a 'pair-instability supernova', which would blow itself to bits before it could form a super-dense core. These things would be amazingly bright and there have been a few observations of events that might be this kind of 'superluminous supernova'."

So, while they may be rare, these monster stars are certainly making their presence felt - and interest is only likely to increase in the next few years. Astronomers believe that supergiants and hypergiants would have been far more widespread in the early universe, when the lack of heavy elements would have given them a more compact structure with a hotter surface. Thanks to the expansion of the universe, the ultraviolet radiation that poured from the surface of these superhot stars should now be stretched or 'Doppler-shifted' to infrared wavelengths. Here it should be visible to NASA's James Webb Space Telescope when it launches in 2018 to give us our first view of the earliest stellar generations.

Hypergiants in our galaxy

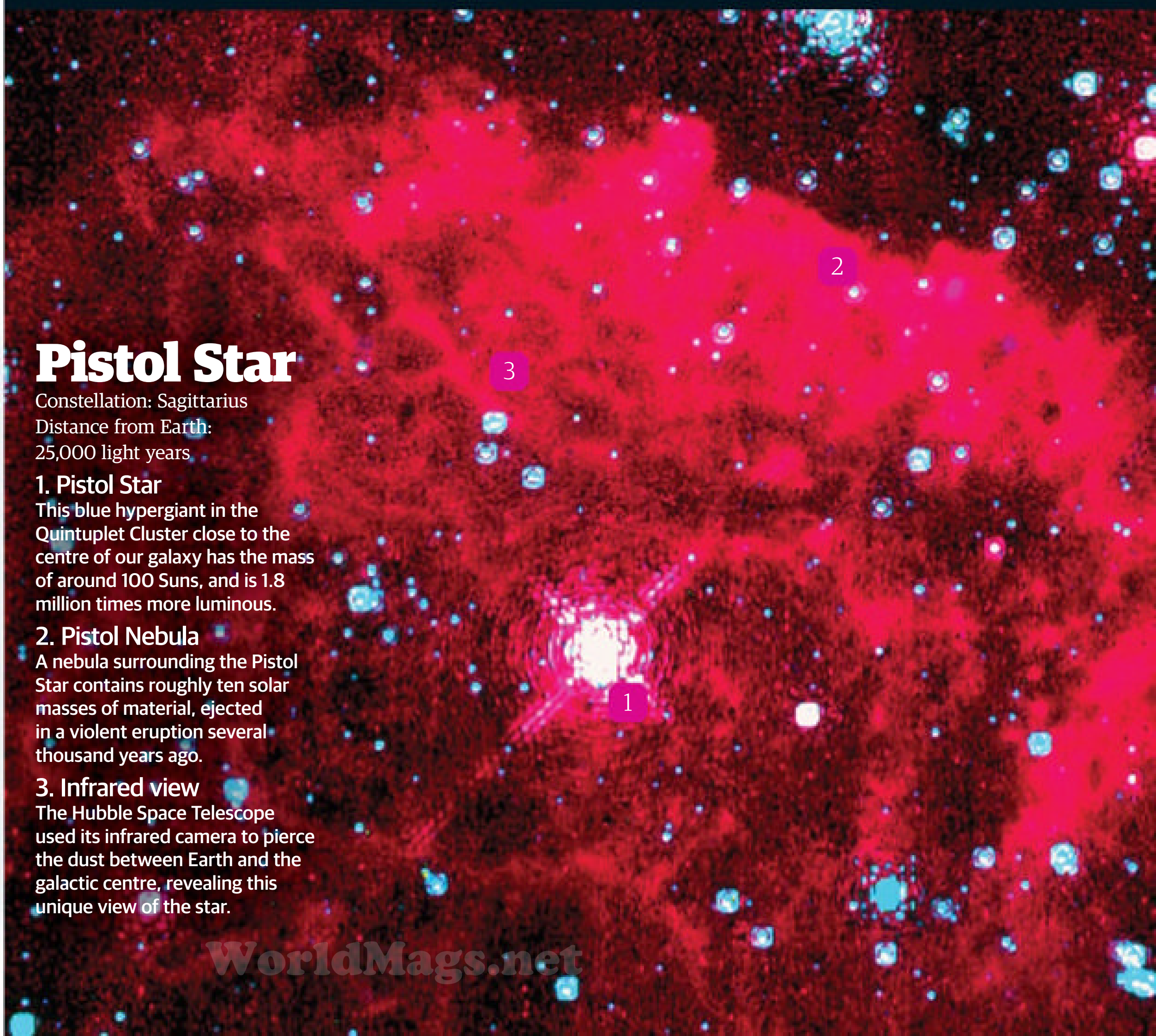
Eta Carinae

Constellation: Carina
Distance from Earth: 7,500-8,000 light years

1. Massive binary
The hypergiant Eta Carinae in the southern constellation of Carina is a binary system in which one star has at least 120 times the mass of the Sun, and is 5 million times more luminous.

2. Violent outbursts
Eta Carinae is prone to sudden eruptions that cause it to brighten unpredictably as it hurtles towards an eventual death as a supernova.

3. Homunculus Nebula
The star is still surrounded by this famous double-lobed nebula, ejected during its last major eruption around 1843.



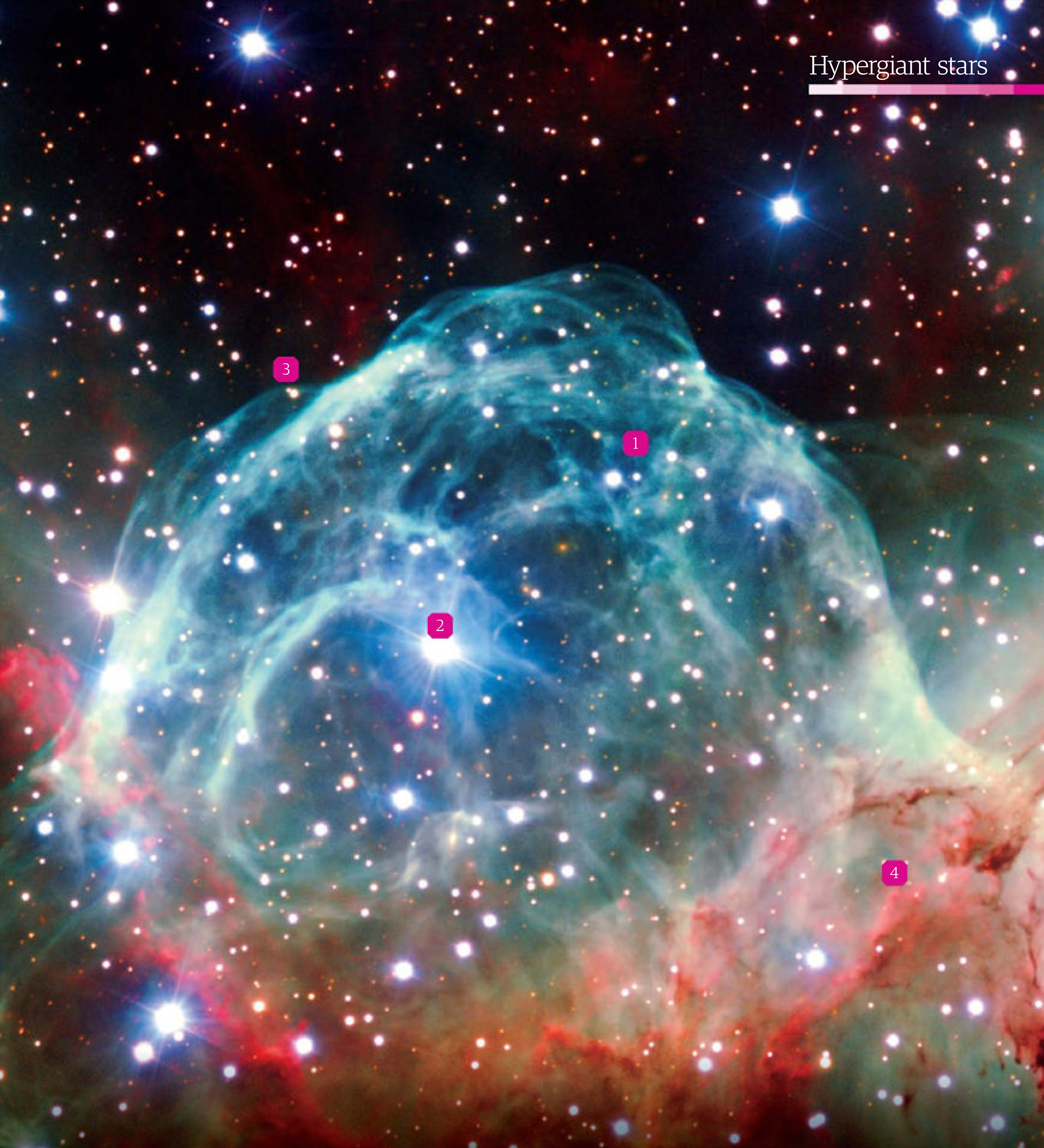
Pistol Star

Constellation: Sagittarius
Distance from Earth: 25,000 light years

1. Pistol Star
This blue hypergiant in the Quintuplet Cluster close to the centre of our galaxy has the mass of around 100 Suns, and is 1.8 million times more luminous.

2. Pistol Nebula
A nebula surrounding the Pistol Star contains roughly ten solar masses of material, ejected in a violent eruption several thousand years ago.

3. Infrared view
The Hubble Space Telescope used its infrared camera to pierce the dust between Earth and the galactic centre, revealing this unique view of the star.



Thor's Helmet

Constellation: Canis Major Distance from Earth: 15,000 light years

1. Thor's Helmet
This distinctive nebula, which is catalogued as NGC 2359, lies 15,000 light years from Earth in the constellation of Canis Major.

2. Wolf-Rayet star
The central star is a blue supergiant with a powerful stellar wind blowing material away off its surface – an object known as a Wolf-Rayet star.

3. Gas shell
As wind from the star collides with the nearby interstellar medium, it is heated and excited to release energy through light, creating a glowing gas bubble.

4. Swept wings
Collisions with interstellar material as the star travels through space create the nebula's distinctive helmet-like wings.